GIS BASED FLOOD HAZARD MAPPING OF KOSI RIVER BASIN, NORTH BIHAR, INDIA

A thesis submitted
in partial fulfillment of the requirements
for the degree of

Master of Technology

by
G.Venkata Bapalu

Department of Civil Engineering
Indian Institute of Technology, Kanpur
June, 2005.

CERTIFICATE

It is certified that the work presented in this thesis entitled **"GIS – BASED FLOOD HAZARD MAPPING OF KOSI RIVER BASIN, NORTH BIHAR, INDIA"** *has been carried out by* Mr. **Venkata Bapalu Ganugula** *(Roll No. Y3103056) under my supervision and has not been submitted else where for a degree.*

June
~~May~~, 2005

Rajiv Sinha

Dr Rajiv Sinha
Associate Professor
Department of Civil Engineering
Indian Institute of Technology Kanpur,
Kanpur - 208016, U.P., India.

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G. V. Bapalu

G. Venkata Bapalu
I.I.T. Kanpur
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GIS based Flood Hazard mapping of Kosi River Basin, North Bihar, India

G.Venkata Bapalu
Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur – 208016, India.
Email: bapalu@iitk.ac.in

Abstract

Flood Hazard Mapping is a vital component for appropriate land use planning in flood-prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation/ response efforts. It is now increasingly realized that it is more rational to try minimizing the risk and damage from floods rather than formulating structural measures along the dynamic rivers such as the Kosi. This thesis presents an efficient methodology to accurately delineate the flood-hazard areas in Kosi River Basin, North Bihar, India in a GIS environment using multi-criteria decision-making technique, Analytical Hierarchical Process (AHP). The basic aim of this effort is to identify the area chronically suffering from river flooding and create a flood hazard map. This thesis describes computing a composite index of flood hazard derived from topographical, land cover, geomorphic and population related data. All data are finally integrated in a GIS environment to prepare a final Flood Hazard map. This flood hazard index computed from AHP method not only considers susceptibility of each area under consideration to be inundated but also takes into account the factors that are inherently related to flood emergency management.

The primary data used for this study came from three sources. The first set of data includes Topographic maps, District level maps, and Census data of 1991 for the regional divisions of Bihar are obtained from the Survey of India, National Atlas & Thematic Mapping Organization (NATMO), and District Statistical Office, Saharsa. The second set of data includes the digital elevation data (GTOPO30), a global digital elevation model (DEM) from U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota. The third set is the remotely sensed data from IRS-1D satellite. This thesis also describes

some of the problems that may be encountered, and provides insight into how this data can be stored and disseminated.

This study was particularly conducted to show the importance of recent advances in mapping technology with the latest spatial modeling tools; as a part of non-structural measures of flood management and the implementation of which helps in reducing short term and long-term damages and to bring awareness among the scientific community on the potential need of this research and significantly increasing their involvement in the flood mapping process. The basic merit of this methodology lies in its simplicity and low cost. This is one of the initial projects attempted; the lessons learned from this pilot effort can be applied to a larger area encompassing the whole Kosi River basin. This thesis work presents the methodology followed and GIS operations for mapping and demonstrates the use of GIS based Flood Hazard Mapping especially in India.

Chapter1

Introduction

1.1 Background and Motivation

Floods are probably the most recurring, wide-spread, disastrous and frequent natural hazards of the world. India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for one fifth of global death count due to floods. About 40 million hectares or nearly $1/8^{th}$ of India's geographical area is flood-prone. The Brahmaputra basin in Assam, the central and lower portions of Ganga Basin in Uttar Pradesh, Bihar and West Bengal and the deltaic region of Orissa are the most frequently flood-prone areas in India. The plains of north Bihar are some of the most susceptible areas in India, prone to flooding. A review by Kale (1997) indicated that the plains of north Bihar have recorded the highest number of floods during the last 30 years. The total area affected by floods has also increased during theses years. Drained by two major rivers, the Kosi and Gandak, and several smaller systems such as Burhi Gandak, Baghmati and Kamla-Balan, the plains of north Bihar have experienced extensive and frequent loss of life and property over the last several decades (Sinha and Jain, 1998). The Kosi River is well-known in India for the flood damages it causes and for the change that occurs in its course almost every year. The Kosi is one of the major tributaries of the Ganga River, and rises in the Nepal Himalayas. After traversing through the Nepal Himalayas it enters India near Bhimnagar. Thereafter, it flows through the north Bihar and joins the Ganga River near Kursela, after traversing for 320 km from Chatra. The river has been causing a lot of destruction by lateral movement similar to the Yellow River in China. As its waters carry heavy silt load and the river has a steep gradient, the river has a tendency to move sideways. Thus, in about 200 years the river has moved laterally by about 112 km (Rao, 1975). To check the lateral movement as well as for flood control, embankments on both sides of the river were constructed, five to sixteen km apart. At present, aggradation is confined within the embankments, and hence, lateral shift is confined within the embankments. But the problem of flooding is still a challenge

in this area. The problem of river flooding is getting more and more acute due to human intervention in the flood plain at an ever increasing scale. It is now increasingly realised that minimizing the risk and damage from floods may be more rational way of flood management rather than formulating structural measures along the dynamic rivers such as the Kosi.

In this scenario, the regulation of flood hazard areas coupled with enactment and enforcement of flood hazard zoning could prevent damage of life and property from flooding in short term as well as long term. Flood management and control are necessary not only because floods impose a curse on the society, but the optimal exploitation of the land and proper management and control of water resources are of vital importance for bringing prosperity in the predominantly agricultural based economy of this diversely populated country. This cannot become technically feasible without effective flood hazard maps. Flood hazard mapping and flood inundation modeling are the vital components in flood mitigation measures and land use planning, and are prerequisites for the flood insurance schemes.

The present thesis seeks to formulate an efficient methodology for accurately delineating the flood-prone areas in the Kosi river basin, north Bihar, India in a GIS environment using one of the multi-criteria decision-making techniques, Analytical Hierarchical Process (AHP). The basic aim of this effort is to identify the areas suffering from river flooding and create easily-read, rapidly-accessible charts and maps of flood hazard based on morphologic, topographic, and demographic data and to explore the techniques for rapid and inexpensive models for flood plain analysis. More specifically, this study is focused on computing a composite index of flood hazard based on multi-parametric analysis and finally integrate all these parameters in a GIS environment to prepare a final Flood Hazard map. These flood hazard maps not only consider susceptibility of each area to inundation but also takes into account the factors that are inherently related to flood emergency management. This thesis presents the methodology followed for data preparation and GIS operations for mapping flood hazard zones in the Kosi basin in north Bihar.

1.2 Scope and Objectives

The scope of the present thesis is to develop a flood hazard map using one of the multi-criteria decision-making techniques in a GIS environment. This study is aimed at demonstrating the importance of recent advances in mapping technology and spatial modeling tools, and to provide a non-structural measure for flood management The basic merit of this methodology lies in its simplicity and low cost., The major objectives of this thesis were set out as follows:

(i) To identify the major factors and sub-factors influencing flood hazard potential in the study area

(ii) To prepare various thematic layers pertaining to each set of factors using remote sensing images, maps and other data sets.

(iii) To integrate all factors in a GIS environment and to develop a suitable ranking scheme for different layers (factors)

(iv) To generate a flood hazard map for the study area

I have chosen a small window in the Kosi basin, north Bihar for this thesis the results of which can be applied to a larger area encompassing the entire Kosi River basin as well as other basins. The present study should help the public and private agencies involved in flood management in the following ways:

- It should help in developing strategies to protect human life, health and property from floods.
- It should minimize the expenditure of public money on expensive and ineffective flood control projects, prolonged business interruptions, damage to public infrastructure, facilities, and utilities and net ecological loss of flood plains.
- It should provide an accurate delineation of the hazard areas for Flood Insurance Programmes which is lacking in our country and will support the public agencies during rescue and relief efforts.

- It should ensure that those who occupy flood hazard areas assume responsibility for their actions and will improve the preparedness of the population at risk.
- It should help in establishing proper legal, financial, technical and organizational measures to reduce the harmful effects of the floods.

1.3 Study Area

The present study has been carried out in lower Kosi River basin and the area is located between 26°8'19.5" North Latitude and 86°10'54.99" East Longitude which includes portions of five districts viz. Saupal District, Saharsha District, Madhepura District, Dharbanga District, and Khagaria District; covering nineteen development blocks. The selection of this study area was primarily governed by the need of a study of the flood hazard zonation in the area in the view of failure of structural measures for containing the river and controlling the flooding. All the development blocks considered are highly populated giving high revenues and wealth to the state of Bihar and are located along the banks of the Kosi River which are frequently affected by the river flooding. The drainage area for the entire basin is 11410 km^2, and the current study area comprising 54.12 km^2.

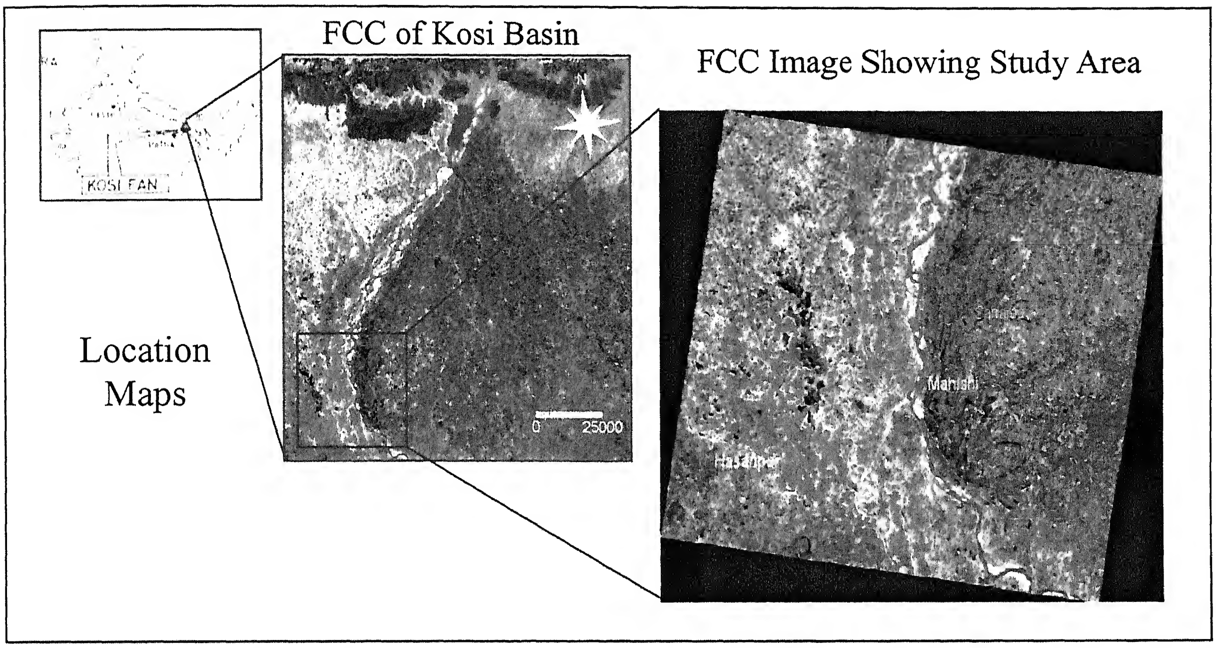


Fig.1.1 Location of the study area.

1.4 Thesis Outline

The research presented in this thesis describes an approach for developing a flood hazard map taking into consideration of various factors and integrating all the data sets in a GIS environment. I have applied a suitable ranking scheme for integrating the various factors. This research also describes some of the problems that may be encountered, and provides insight into how this data can be stored and disseminated. This thesis is divided into six chapters. Following the introduction, a literature review is presented in chapter 2 outlining the status of flood studies using remote sensing and GIS across the world and in India. Chapter 3 presents information on the data sets that were used in the thesis, methodology followed and the operations carried out for image processing and GIS analysis. Chapter 4 provides the results and interpretation of the thematic layers generated for flood hazard zonation. The results of GIS based analysis using AHP method for preparation for final flood hazard map have been presented in Chapter 5. The final chapter 6 presents the summary and conclusions of the thesis and provides some recommendations for future flood management and mitigation projects.

Chapter 2

Literature Review

2.1. The Kosi Basin

The Kosi river basin is located in north Bihar plains flanked by the Mahananda basin to the east and the Gandak basin to the west. The Kosi river catchment is spread out in the Himalayan region of Nepal and Tibet and debauches in the plains of north Bihar close to the Indo-Nepal border. About 70% of the total catchment area is under permanent glaciers and snow. The average annual rainfall of the basin in the north Bihar plains is around 140cm and most of this rain fall is concentrated during the months of June to September.

Lateral migration, bank erosion and overbank flooding are among the major fluvial processes operating in the area. These processes are very rapid and the extent is severe; so much so that they are regarded as major "fluvial hazards" in the area (Sinha, 1998). Significant damages due to recurrent occurrence of floods in the basin occur on account of damages to crops, to houses, to public utilities and to cattle population (Table 2.1). Loss of human lives due to floods also occurs but it can only be considered as intangible flood damage. The construction of embankments along major portions of the Kosi river is only a short-term solution to mitigate floods not only because of frequent breaches in the embankment due to extremely high discharges during high flows but also because of the fact that this river carries a high sediment load causing rapid siltation and thereby raising the water level in a few year's time (Sinha, 1998). Engineering measures taken to prevent these fluvial hazards in the area have largely failed which often creates havoc in the area.

Table 2.1: Damage report due to flood in Bihar as on 14th July, 2004

Number of districts affected	16
Number of Blocks affected	113
Number of villages affected	3652
Population affected	94.36 lakh
Area affected	39.982 lakh hectares
Crop area affected	8.418 lakh hectares
Number of houses damaged	2.38 lakh
Human lives lost	32
Number of livestock lost	17

(Source: http://www.reliefweb.int)

2.2 Current Flood Mapping Techniques

The standard methodology for flood hazard mapping includes two basic steps viz. hydrology and hydraulic (or "H&H") study. The first step is basically a discharge-based flood frequency methodology which begins with a hydrologic analysis to determine the stream flow associated with various flow probabilities (e.g. the discharge that has 1% chance of occurrence in a given year is often called the 100-year flood). The second step uses a hydraulic model such as Corps of Engineer's HecRas (River Analysis System) or UNET (Unsteady Flow in a Network of Open Channels) to convert the estimated discharge flow values into flood heights which are compared to associated lands to map the floodplain. The result of this analysis is a flood profile associated with a given flood probability for the river reach.

Standard techniques use manual methods to delineate the extent of flooding. However, the usage of computer automated methods with hydrologic data, existing hydraulic models, and digital terrain models of the floodplain in conjunction with GIS are becoming increasingly common in most flood-affected countries. While these H&H

procedures produce important data related to flood hazards, the process is extremely resource intensive and expensive. The deterministic models are data intensive and require detailed stream channel characteristics such as channel geometry and roughness (Pinter et al., 2001).

Research conducted by Benito et al. (2004) shows that there are also other means of estimation of flood risk. Past flood information obtained from palaeoflood hydrology (based on geologic indicators) and from historical information (based on documents and chronicles) provide a catalogue of the largest flood events that occurred during periods of settlement. While palaeoflood investigations using palaeostage geological indicators can document the magnitudes of the largest floods over well defined periods of time (usually from decades to millennia), and provide evidence of all other events below or above specified flow stages or thresholds (Stedinger and Baker, 1987). Long records of extreme floods are then applied successfully in risk analysis together with the more traditional empirical, statistical and deterministic methods to estimate the largest floods. These extreme floods are the ones the planners and engineers are most interested in but are very rare in the observational record (Enzel *et al.*, 1993).

2.3 Remote Sensing based studies on Flood Hazard Mapping

Natural disasters like floods happen every year and their impact and frequency seem to have greatly increased in recent decades, mostly because of environmental degradation, such as deforestation, intensified land use, and the increasing population. Traditional methods of flood mapping are based on ground surveys and aerial observations, but when the phenomenon is widespread, such methods are time consuming and expensive. Furthermore, timely aerial observations may be impossible due to prohibitive weather conditions.

In recent decades, optical remote sensing data acquired by sensors onboard spacecraft have been used in many studies to map inundated areas over regions characterized by very different conditions in climate, morphology and land use. Use of this remote sensing

technology is of interest because of its ability to (a) provide information on a timely basis, (b) provide large volumes of information in a cost effective manner, (c) acquire information for hazardous or inaccessible regions, and (d) monitor areas and events non-intrusively.

These approaches for flood inundation mapping have involved digital or visual analyses of System Probationer Observation Terre Multispectral (SPOT XS) scenes of Europe and Asia (Robin and Le Rhun 1989, Blasco *et al.* 1992), Landsat Thematic Mapper (TM) data in North America (Lougeay *et al.*, 1994) and Landsat Multispectral Scanner (MSS) images of West Africa (Brivio *et al.*, 1984, Zilioli *et al.*, 1993). Thermal data collected during the night-time by NOAA-9 AVHRR (National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer) were also used by Barton and Bathols (1989) to map the extent of flooding in central Australia. An estimate of the extent of flooded areas was conducted by Berg *et al.* (1981) using the NOAA satellite thermal infrared sensor. Despite their coarse spatial resolution, AVHRR images have the advantage of high temporal resolution, and sometimes are the only available source of information. Bad weather conditions during and after flood events can represent a strong constraint to the utilization of optical remotely sensed data. For this reason, optical sensors are generally used to assess inundated fields only some days after the event, either by recognition of fluvial sediments left on the land (Rosso, 1995) or by the detection of vegetation stress (Michener and Houhoulis, 1997). On the contrary, spaceborne radar systems, because of their exclusive cloud penetration capacity, offer a primary tool for real-time assessment of flooded areas. Different methodologies have been developed using special sensor microwave imager SSM/I (Tanaka *et al.*, 2000) or single-band (Sharma *et al.*, 1996) and multi-frequency synthetic aperture radar (SAR) data (Ormsby *et al.*, 1985, Hess *et al.*, 1995). The disadvantages of the use of radar sensors lie in the difficulty in classification of the acquired signal because of the influence of complex ground and system variables. If radar images are acquired some days after the event, when only a few areas are still submerged by water, it is advisable to use a multi-sensor approach. In this case, flooded areas as derived from radar data are complemented with information extracted from optical images, such as the aerial extent

of fine material left during the flood (Imhoff *et al.,* 1987; Bonansea, 1995). Another possibility is the integration in a Geographical Information System (GIS) of radar imagery acquired during the flood event with information derived from digital topography (Giacomelli and Mancini, 1996; Brakenridge et al., 1998).

2.4 GIS in Flood Hazard Mapping

Geographical information systems offer many advantages which make them particularly well suited for floodplain analysis including its ability to store spatial data and attribute information, perform overlay analysis, thorough editing capabilities, and powerful visualization capabilities. For these reasons, GIS is becoming an accepted data storage and analysis platform over traditional approaches (Dodson and Xiaojian, 2000; Andrysiak and Maidment, 2000). Yang and Tsai (2000) describe how a GIS can serve as a flood information system including floodplain modeling, flood damage calculation, and flood information support. Moreover, one important part of FEMA's (Federal Emergency Management Agency) Map Modernization Program is the creation of Digital Flood Insurance Maps (DFIRM). The DFIRM's are spatial databases which store the digital version of the FIRM map(s), data used to produce FIRM map(s), and the engineering information used to determine the floodplains (more information about DFIRM databases are available at: http://www.fema.gov/mit/tsd/MM_DFDB.htm). A GIS approach can serve at many levels of flood-hazard identification, visualization, and storage of both spatial and non-spatial data.

2.5 Flood hazard mapping in India

Flood mapping through satellite remote sensing has been successfully carried out in India (Ramamurthy, 1989; Hooda et al., 1995; Chaudhary et al., 1996). The issue of flood hazard mapping and flood management in India has been addressed from different perspectives to achieve cost effective and other means of identifying and managing the hazard areas implementing non-structural remedial measures.

The application of different data sets like Census data, hydrological data, topographical and other relevant statistical data about the available infrastructure facilities from the government agencies have been used to identify the flood hazard areas in a cost effective manner for the parts of Gangetic West Bengal (Sanyal et al., 2003).

The above application was followed by the usage of historic flood events of 1988, 1995 and 1998 data with the digital data of physiographic divisions, geologic divisions, land cover classification and population density for data poor Bangladesh to develop a comprehensive flood hazard map and land development priority map (Islam et al., 2000). Here, an attempt was made to construct a map for land development priority taking into consideration of flood-affected frequency and flood depths as hydraulic factors (which are found from NOAA AVHRR images), and population density. The NOAA AVHRR data was found very useful for monitoring large surface phenomena, such as floods, in the fields throughout the world on local, regional and international scales while ERS, MOS, Landsat and SPOT has been used to observe regional or local floods. Furthermore, the routine measurement and estimation of hydrological parameters including flood-related parameters could be useful in the areas ranging from global scale to local or regional scale, depending on the spatial resolution and recurrent period (Schultz, 1994).

Attempts have been made to compute the flood levels from the standard manual methods like Gumbel's Method, Log Pearson Type - III Method for flood frequency analysis in conjunction with GIS and digital elevation data for flood risk zone mapping of Dikrong sub basin in Assam (Sarma, 1999).

Remote sensing data in conjunction with the topographical maps and field investigations have been used to find the variation in the configuration of the Sarda River system (one of the major rivers of the Ganga Plain) in space and time (Mitra et al., 2005). In this study, the chronology of channel avulsions and lateral migration has been established and its future course of avulsion is predicted. The process of avulsion in channels is invariably associated with the fluvial hazards.

Space technology has made substantial contribution in every aspect of flood management such as preparedness, prevention and relief (Rao, 1994). In India, Optical and microwave data from IRS, Landsat and ERS satellites are being used to map and monitor flood events over the entire country in near real-time on operational mode and the information is being furnished to departments concerned so as to assist in organizing necessary relief measures and to make a reliable assessment of flood damages.

2.6 Gaps in knowledge in Indian context

Mapping flood hazard is not a new endeavor in the developed countries of the world. However, a closer look reveals that these hazard maps are very data intensive in nature and primarily depend upon very high resolution terrain data. In the current state of technology and resources possessed by India, the preparation of such hazard maps is not feasible. Islam et al (2000a) formulated a methodology to prepare flood hazard map for data poor Bangladesh. There are no appropriate flood hazard maps for any parts of the country and flood mitigation and relief efforts have mostly failed in their implementation. Wherever the maps are available, they are of very regional scale and do not provide any details regarding the parameters used for hazard assessment. Also, these maps are completely knowledge based. There is no standard procedure or demand for the flood insurance program in India and the lack of flood hazard maps has so far constrained the development and implementation of such schemes. The future perspective of this thesis lies in sharing the information to the public and to extend to study area to the entire Kosi basin to build a comprehensive GIS based flood hazard model.

Chapter 3

Data Description and Methodology

3.1 Data Description

The primary data used for this study came from three sources. The first set of data including topographic maps, district level maps, and census data of 1991 for the regional divisions of Bihar was obtained from National Atlas & Thematic Mapping Organization (NATMO). The second set of data includes the elevation data (GTOPO30) from the USGS global digital elevation model (DEM) for a regional analysis and the spot heights on the topographic sheets of the Survey of India for detailed analysis. The third set is the remotely sensed data from IRS-1D satellite which was used for land cover, vegetation and geomorphic mapping. The purpose of this chapter is to describe the input data, software's used and problems faced during data conversion and the basic methodology followed in the thesis work for generation of flood hazard map..

3.1.1 Maps

The data sources and scale for the topographic and district level maps are tabulated in detail in Table 3.1

Data Type	Details	Data Source
1. Topographic Maps		
1. 72 K	Scale: 1:250,000	Survey of India, 1984
2. 72 J	Scale: 1:250,000	Survey of India, 1983
2. District Planning Map Series		
1. Dharbanga District Map	Scale: 1:250,000	National Atlas & Thematic
2. Madhepura District Map	Scale: 1:250,000	Mapping Organization
3. Khagaria District Map	Scale: 1:250,000	(NATMO), 2001.
4. Samastipur District Map	Scale: 1:250,000	
3. Saharsa District Map	Scale: 1: 1000,000	District Statistical Office, Saharsa, 1981.

4. Bihar in Maps	Scale: 1:1000,000	National Atlas & Thematic Mapping Organization (NATMO), 2004.

3.1.2 Digital Elevation Data (GTOPO30 DEM data)

The digital elevation data used in this research for visual analysis was the GTOP30 DEM (global digital elevation model) data from the U.S. Geological Survey's EROS Data Center and the DEM of the study area was derived from contour data prepared from the topomaps. Therefore, this data set has been used to extract topographic features like slope, aspect, and relief of the study area and also served in identifying some of the geomorphic features of the study area.

GTOPO30 is a global digital elevation model (DEM) resulting from a collaborative effort led by the staff at the U.S. Geological Survey's EROS Data Center in Sioux Falls, South Dakota. Elevations in GTOPO30 are regularly spaced at 30-arc seconds (approximately 1 kilometer). GTOPO30 was developed to meet the needs of the geospatial data user community for regional and continental scale topographic data. This release represents the completion of global coverage of 30-arc second elevation data that have been available from the EROS Data Center beginning in 1993.

GTOPO30 is a global data set covering the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal grid spacing is 30-arc seconds (0.008333333333333 degrees), resulting in a DEM having dimensions of 21,600 rows and 43,200 columns. The horizontal coordinate system is decimal degrees of latitude and longitude referenced to WGS84. The vertical units represent elevation in meters above mean sea level. The elevation values range from -407 to 8,752 meters. In the DEM, ocean areas have been masked as "no data" and have been assigned a value of -9999. Lowland coastal areas have an elevation of at least 1 meter, so in the event that a user reassigns the ocean value from -9999 to 0 the land boundary portrayal will be maintained. Due to the nature of the raster structure of the DEM, small islands in the ocean less than approximately 1 square

kilometer will not be represented. False Colour Composite (FCC) image was overlaid on the elevation data from GTOP30 DEM data for visual analysis and interpretation of some of the geomorphic and other topographic features.

Another set of elevation data used for the work is the spot heights from the Survey of India topographic sheets. A DEM for a part of the Kosi basin was generated using ILWIS image processing software with the help of 1017 spot heights from 1:50,000 scale toposheets of the period 1972-75. The total elevation range in the study area varies from 32 to 50 meters. The data source and its description for the study area are shown in Table 4.1. The entire region is a plain having a gentle slope from north-west to south-east. Therefore, this data set has been used to extract topographic features like slope, aspect, and relief of the study area and also served in identifying some of the geomorphic features of the study area.

3.1.3 Remote Sensing Data

In the present work, IRS-ID satellite data covering the Kosi alluvial plains were used. The details of the data, supplied by National Remote Sensing Agency, Hyderabad, are given below:

Satellite	: IRS-I D
Sensor	: LISS III
Path/Row	: 6300/6020
Date of Pass	: 7 March 2002
Data format	: BSQ
Bands	: 2, 3, 4 and 5
Swath	: 70 KM

The spatial and spectral resolution of the LISS III sensors is tabulated in Table 3.2.

Table 3.2: Spectral and Spatial Resolution of the LISS III Sensor

Band	Spectral Resolution (μm)	Spatial Resolution (m)	Principal Application
Band 2 (green)	0.520 – 0.590	23.5	Green reflectance peak for healthy vegetation
Band 3 (red)	0.620 – 0.680	23.5	Sensitive to chlorophyll absorption, discrimination of soil and geological boundary
Band 4 (infrared)	0.770 – 0.860	23.5	Sensitive to biomass, land water contrast, soil moisture discrimination
Band 5 (thermal)	1.550 – 1.700	70.5	Soil and vegetation moisture, differentiation of snow and cloud

3.1.4 Census Data

The census data of 1991, for the present study contains Regional Division Data of Bihar, from which the population data of the 19 development blocks in 5 districts was used. It also contains other data which can be used for any other analysis.

3.2 Methodology

3.2.1 Approach

Thematic maps for various factors controlling the flood hazard in the Kosi River basin were prepared through remote sensing data, topographic maps, district level maps, census data, and DEM data. The factors identified are population density, distance, elevation, land use, vegetation, and geomorphic features. The sequence of investigation included map analysis, remote sensing data analysis, and DEM data analysis (Fig 3.1). The available topographic maps, district level maps combined with census data were analyzed to derive information on land use, geomorphic features and population density. The available DEM data was analyzed to derive information on slope, relief and aspect of the

study area. All the data layers derived from various sources were converted into digital form to be available for GIS analysis. Digital remote sensing data (LISS-III sensor, of spatial resolution 23.5m) was analyzed to derive information on land use, vegetation, and geomorphic features supported with available maps. All maps and data obtained through image processing and digitization were analyzed in a GIS environment for development of suitable algorithm for multi-criteria decision making for identification of flood hazard zones. A technique for quantitatively assessing the hierarchical weightage of each factor controlling flood hazard was used based on Analytical Hierarchical Process (AHP). A detailed discussion on AHP is presented in subsequent chapters.

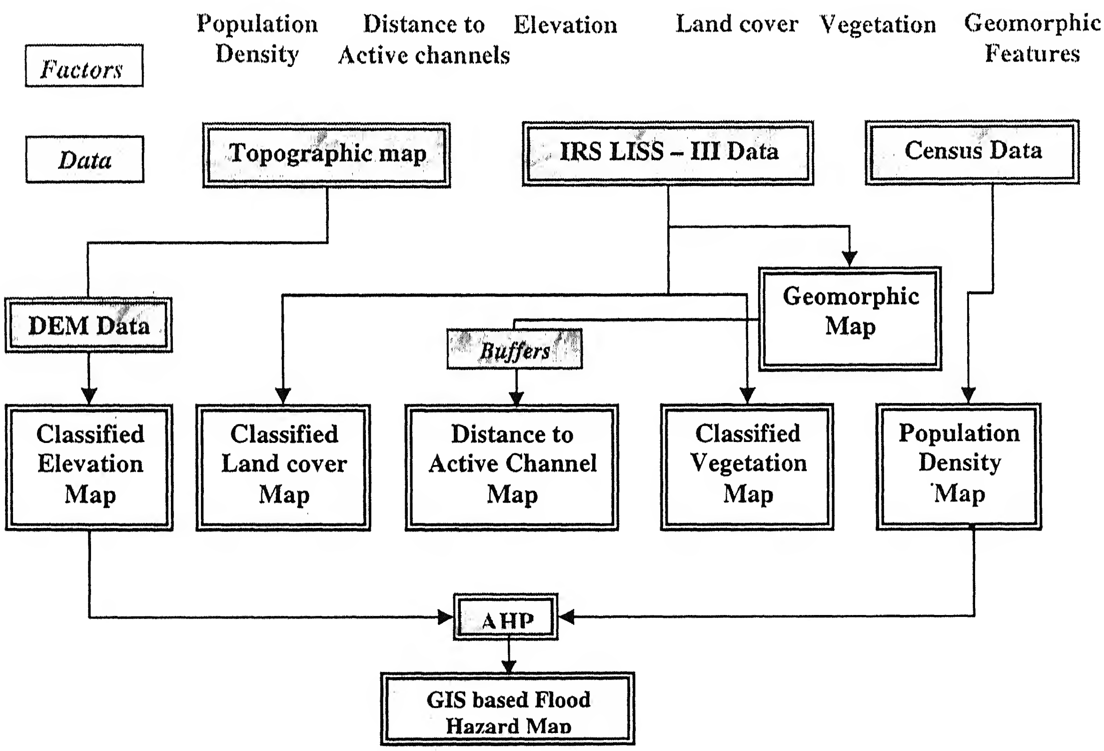


Fig 3.1 Methodology of the present work

Table 3.3 shows various image processing and GIS software's used in thesis work.

Table 3.3 Image processing and GIS software's used in thesis work

Image Processing software	GIS Software
ENVI 4.0	Arcview GIS 3.2a
ERDAS Imagine 8.5	Arcview GIS – Spatial Analyst Extension with Model Builder
ILWIS 3.1	Arcview GIS – 3D Analyst Extension

3.2.2 Data Management and Data Conversion

Data management, data conversion, and data preparation are some of the most important aspects for successful implementation of the project at hand; particularly for any GIS-assisted applications. In this research, certain problems were faced when working on data from different data sources in Arcview GIS environment. The problems faced during execution have been solved by adopting usage of software's like ENVI 4.0, ERDAS 8.5. The explanation and recommendations for flexible implementation of work is presented in this section briefly. Conflicts among data management, data conversion, and data preparation arose when working in different environments, when software's can not support large number of formats. Understanding these conflicts is important for practical implementation of the algorithms and models and to achieve the desired accuracy. Image analysis and data processing techniques were required for developing various thematic layers; and for subsequent analysis and modeling in the GIS environment. It is necessary to use different Image Processing and GIS software's for certain operations (like georeferencing, image registration, mosaicking, etc...) to make the work environment more flexible and efficient.

Some of the practical problems faced when using the image processing software ILWIS 3.1 are as follows:

- Even though the image processing, editing and analysis capabilities are good in ILWIS, the drawback observed is that it could not support different formats and also can not export to any desired format. It confines the usage of formats which is very important when using different software's for the work at hand.
- When files are exported in TIFF/GEOTIFF format, the exported data could not carry the geo-referenced information along with it. So, it is important to see the format support by the software for ease of work.
- The export/import options are not flexible and can not support commercial GIS software formats.

3.2.3 Georeferencing and Registration

Ordinarily, the first step in overlaying different data sources for comparison and analysis would be to *georeference* them. Georeferencing is a process where one identifies similar points on different data sets, and assigns these points comparable spatial and identity information. Then, the next step is to rotate, scale, and "rubbersheet" different data layers so that they can overlaid upon each other; this process is called "Registration". The topo maps (72J, 72K) of 1:250,000 scale, district level maps of 1:250,000 scales, and LISS-III remote sensing data have been georeferenced using control points collected from the tops maps and are projected in Geographic (Lat/Long) system with WGS 84 as their reference Spheroid and Datum.

3.2.4 Geographic Information System (GIS) and sequence of operations

Geographic Information System (GIS) was used for data processing described in this thesis. Although there are many different definitions of GIS, it can be thought of as a computer system for storing, viewing, editing or analyzing geographically referenced data. GIS is used for many purposes, such as traffic planning, water and electric utility design, and law enforcement. It is an important tool in water resources engineering because of the spatial nature of water resources problems.

ArcView 3.2a and its extensions like Spatial Analyst, 3D Analyst, Model Builder developed by the Environmental Systems Research Institute, Inc. (ESRI), are the GIS software packages used for this thesis. ArcView provides a visual environment for viewing and manipulating data in intuitive ways. In this thesis, ArcView 3.2a was used for working with grids and shapefiles.

Keeping in view the above constraints and limitations of the data management and software, I have followed the following sequence of operation:

Firstly, the DEM of the study area was generated using the spot height data collected from the topomaps in ILWIS 3.1 Image Processing software. Then, it was converted into a point map and exported into ArcView GIS; where this vector elevation map is converted into raster grid format for overlay analysis.

Secondly, the satellite imagery is georeferenced and registered to the geographic space. On this georeferenced image, image classification algorithms like GMLC, NDVI are applied to extract the land cover and vegetation information. Also, onscreen digitization process was carried out to delineate the geomorphic features from the image. All these classified and processed images are then exported into ArcView GIS for conducting overlay analysis.

Thirdly, demographic data like population density (delineated from Census data in ArView GIS) is also included in the overlay analysis. Some extra GIS operations like buffering was applied on above obtained date to derive some new important data which in turn used in overlay analysis.

Finally, all data was integrated in a GIS environment using AHP method for generating the flood hazard map.

Chapter 4

Generation of Thematic layers for Flood Hazard Zonation

4.1 General

Thematic maps for various factors controlling flood hazard in the Kosi River basin were prepared through digital remotely sensed data, available maps and census data. As mentioned in Chapter 3, these factors included elevation, land use, geomorphology, vegetation, distance to active channels, and population density. This chapter first describes the rationale for the choice of different variables used for the study. This is followed by description of procedures required for the preparation of flood hazard map of the study area using GIS. This database preparation, integration of thematic layers and the overlay analysis in GIS are the important steps in the research conducted. It was decided that this overlay analysis should be conducted in ArcView GIS with extensions Spatial Analyst, 3D Analyst, and Model Builder and also to integrate all the thematic layers from various image processing software's into a single known ArcView GIS format which was one of the challenges faced in the process.

In the current study, the issue of flood hazard mapping has been addressed from the perspective of regional mapping scale in a GIS environment. In this scenario, administrative units have been selected as the unit of investigation. A flood hazard map based on administrative units is particularly handy for the planners and administrators for formulating remedial strategy. It also makes the process of resource allocation simple resulting in a smooth and effective implementation of the adopted flood management strategy. The aim of regional study is to broadly identify the high hazard areas in the lower Kosi River basin. A regional study eventually leads to identification of the higher hazard zone in the area. A more detailed and high resolution study of this zone optimizes resource allocation and saves time.

The basic aim of this effort is to identify the areas chronically suffering from river flooding and create a flood hazard map based on topographic, demographic, geomorphic related data in a GIS environment.

4.2 Choice of variables

The basic unit of this study is the development blocks in five districts of Darbhanga, Saharsa, Khagaria, Madhepura and Madhubani in north Bihar. A development block is the smallest administrative unit in India as far as water resource management is concerned. Special attention has been given to administrative units rather than physical units because socio-economic variables are recorded for the administrative units and any remedial measure taken on behalf of the concerned ministry is implemented at the administrative unit level. In technical terms, this study is focused on computing a composite index of flood hazard based on topographic, demographic, geomorphic and land cover data. All data have been integrated in a GIS environment. This index not only considers susceptibility of each block to be inundated but also takes into account the factors that are inherently related to flood emergency management.

For the regional study, a total of 19 development blocks covering 5 districts have been analyzed. Therefore, the hazard map is not expected to depict any finer detail. At a regional scale, six factors have been taken into consideration for developing the composite flood hazard index namely population density, distance to active channels, elevation, vegetation, land cover, and geomorphic features. Each of the factors has been assigned different weightage using a multi-criteria decision making technique known as Analytical Hierarchical Process (AHP) to quantify the severity of the flood hazard.

4.3. Preparation of Thematic Layers and their description

This section describes the image processing techniques and GIS operations applied for the generation of various thematic layers containing various factors controlling flood hazard of the lower Kosi basin, and most importantly, the data conversion of various

thematic layers into a single known GIS format is also discussed. Each layer and its categories have been assessed in terms of flood hazard.

4. 3.1 Geomorphic Features

In the study area, various geomorphic features have formed by different fluvial processes. A geomorphological map of the study area was prepared by digitizing the features from the remote sensing image. These features are active channels, inactive channels, dry channels, crevasse deposits, water-logged areas, channel bars, sand patches, ox-bow lakes, and flood Plain as shown in Fig 4.1. Geomorphological features in the study area which have high potential of undergoing many changes due to severe water erosion are identified and mapped. Hence, this variable has been considered as the measure of flood hazard of a particular block and it is named as 'Geomorphic Features'.

Different geomorphic features are identified on the satellite image and mapped by onscreen digitization process in ArcView GIS; all the features on the satellite image are digitized in conjunction with the topographic maps. Different codes and colours were assigned to identify them easily and the finally prepared map is in *.shp format of Arcview GIS. In order to conduct overlay analysis, all the thematic layers should be in a raster grid format. So, the geomorphic features in *.shp format is converted into GRID format for ease of use in overlay analysis.

The most important geomorphic feature seen in figure Fig 4.1 is the Kosi river channel and megafan characterized by several paleochannels of the Kosi towards the east of the present channel. The Kosi river flows NE-SW after it debauches in the plains and then takes and SE turn and meets the Ganga river downstream. The Kosi is a clearly braided river showing channel bars all along its course. The primary channel shifts its position from the left to right bank along the course of the river. The other important river channels flowing in the region are the Kamla-Balan system and the Baghmati river; the former meeting the Kosi and the latter meeting the Ganga river. The Kamla-Balan and Baghmati are essentially meandering rivers and show a number of meander cut-offs and ox-bow lakes suggesting local migration apart from several paleochannels. The Baghmati river shows very sinuous course in several reaches and consequently the frequency of

meander cut-offs is much more in its floodplain. Many of the sand patches cutting across the present-day channels represent the crevasse deposits and indicate the locations of frequent breaching of the river banks. Low-lying areas in the floodplains are marked by large water-logged patches (backswamps) sometimes bordered by salt-encrusted areas indicating drying up of these areas. Many of these areas are permanently water-logged and get filled up quickly during monsoon. They are also fed by several smaller inactive channels which get connected to the active channels during the monsoon.

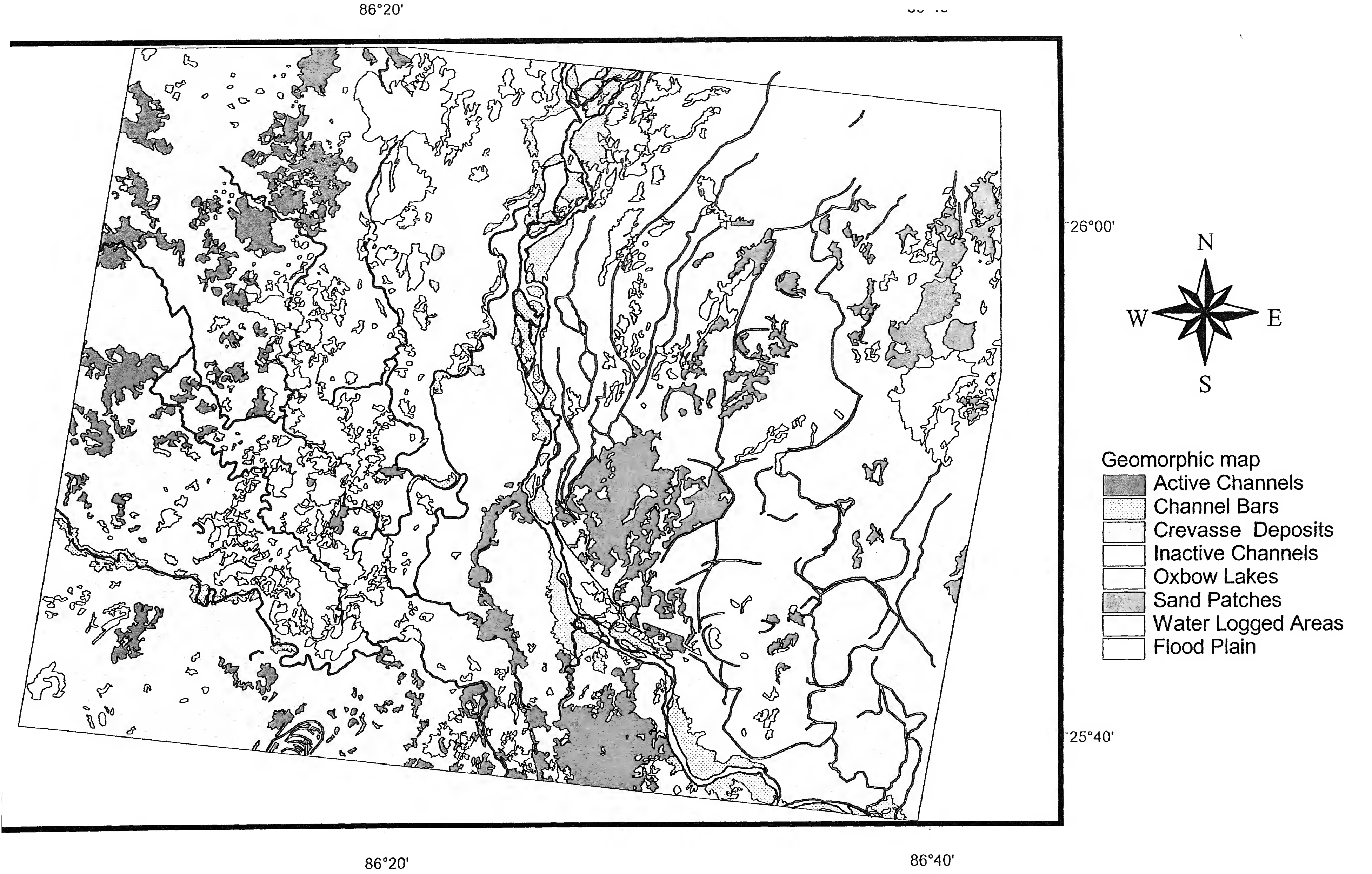


Figure 4.1 Geomorphic Map of the study area

4. 3.2 Population Density

To quantify the economic assets under potential flood threat, population density of the development blocks has been chosen as an important variable. Population density figures have been collected from Census of India, 1991. Later in this thesis, this variable will be identified as 'pop-den'. These variable suite with the current frame work of investigation as the population data is collected in micro and macro regional levels of the districts of Bihar by the Census Department, New Delhi.

Digital population data was mapped in Arcview GIS in *.shp format using population density map of Census, 1991 for the districts of Bihar. Then this *.shp file is converted into *.grid format for use in overlay analysis. The digital population density data was categorized into three categories viz. 401-700, 701-1000, >1000 depicting macro and meso regional divisions of districts of Bihar as shown in Fig. 4.2. High population density figures of >1000 , 701 – 1000 are observed in the district of Dharbanga compared to less population density of 401 – 700 in districts of Saharsa, Madhepura, Khagaria and Madhubani. Most parts of the study area have the population density of 401-700 and 701-1000.

4.3.3 Land Cover

One of the essential components of flood mitigation strategy is the land cover of the area that is going to be affected during times of flood. For proper mitigation and faster evacuation of the affected community, it is essential to identify the areas of high flood hazard. A land cover map was generated from the satellite image through image classification procedure and was considered as one of the thematic layers for the analysis. The land cover map was validated through topographic maps from Survey of India and the National Atlas and Thematic Mapping Organization (NATMO), Kolkata. This variable was assigned the name as 'Land Cover'.

The features identified as important parameters under the land cover layer are running water bodies, agriculture, moist sand, channel bars, and water logged areas. Firstly, supervised classification was carried out for the IRS LISS III data using Gaussian

maximum likelihood classification (GMLC) method. The GMLC classifies an image based on the information contained in the training samples collected and produces a classified image of the Land Cover as shown in Fig. 4.3. The classified image is showing all the features mentioned above and the overall accuracy was computed as 76.22%. This image classification process was carried out in ILWIS image processing software and then this image in ILWIS format is exported into *.bmp format. Problems with some image formats (*.bmp and *.tiff) is that they would not take the georeferencing information with them while transferring data and also the final image obtained was not in a single band file losing pixel information for conducting overlay analysis. Severe problems were faced during this process using various image formats. It was observed that in order to get the final image in a single band file, it is better to export the image into *.bmp format as it gives the final image in single band format, though it loses georeferencing information and then georeference and register it using any image processing software like ERDAS IMAGINE, ENVI. This *.bmp file of land cover is then converted into *.grid format in Arcview GIS for overlay analysis. The important point to be considered here is that this GRID file should be in discrete form rather than continuous form to conduct AHP analysis.

To assess the accuracy of an image classification, it is a common practice to create a confusion matrix. In a confusion matrix, our classification results are compared to additional ground truth information (such a map is also known as the test set). The strength of a confusion matrix is that it identifies the nature of the classification errors, as well as their quantities. For the current classified image of the study area, confusion matrix is computed and the overall accuracy obtained from the confusion matrix is 76.22%.

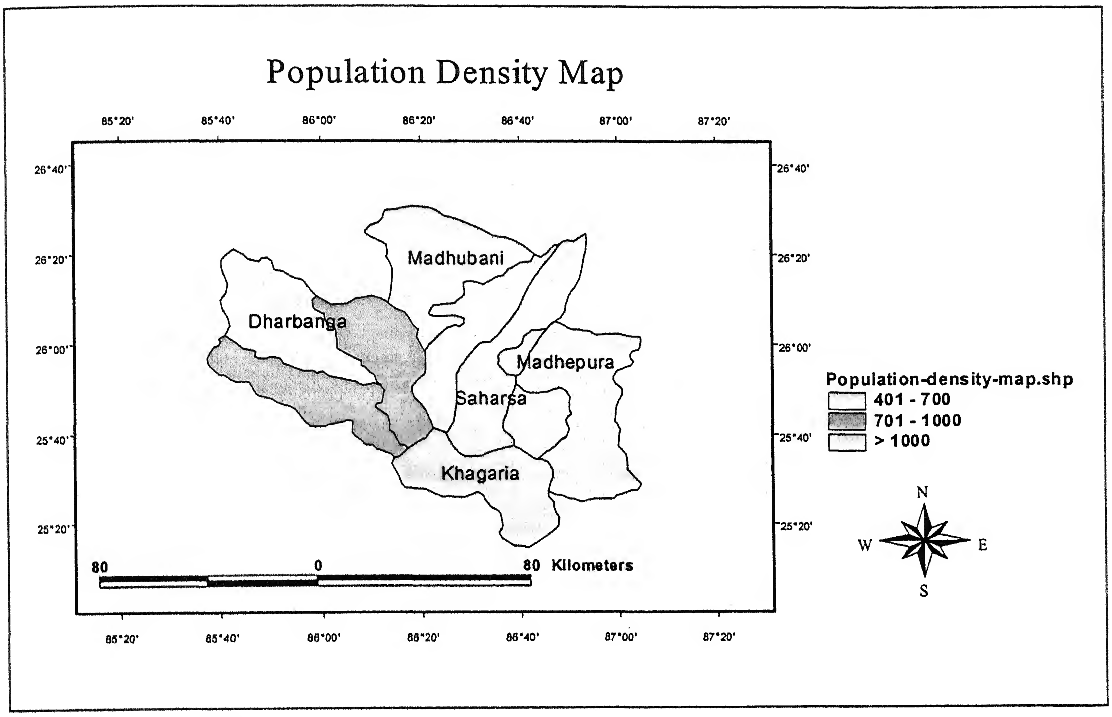


Fig. 4.2 Population Density Map of the study area

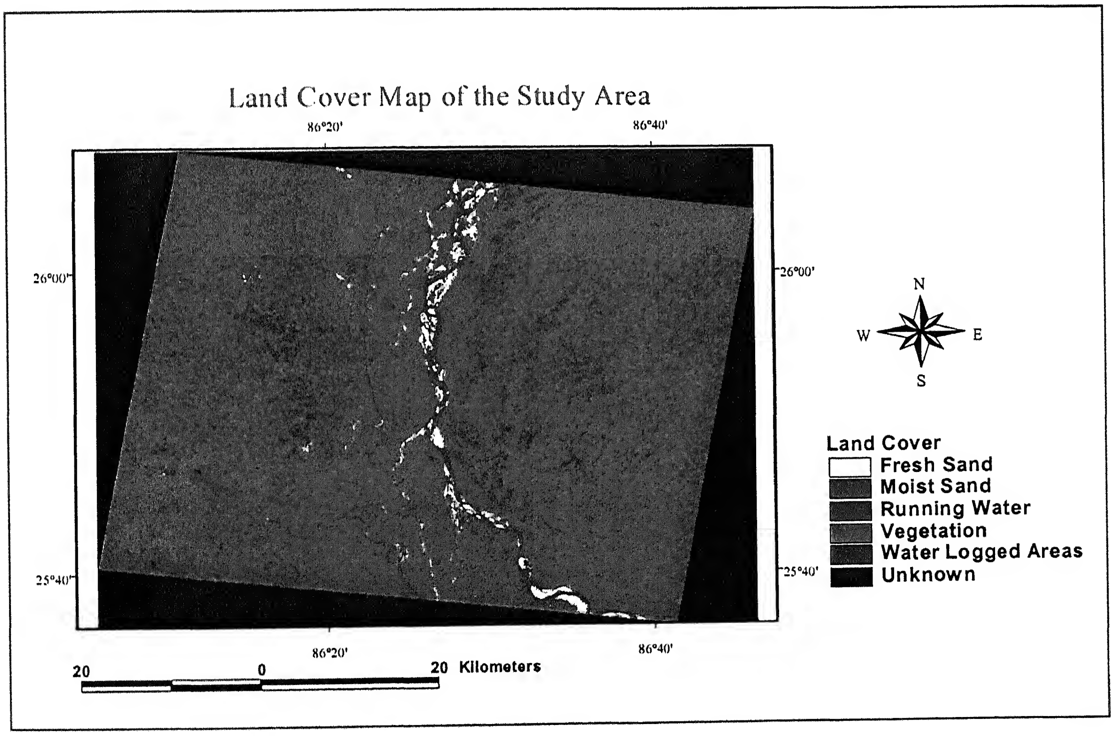


Fig. 4.3 Land Cover map of the study area

4.3.4 Elevation

Elevation in the Kosi River basin was considered as one of the important variables for the assessing the flood hazard. The north Bihar plains are characterized by two mega fans, the Kosi and the Gandak mega fan. These mega fans are sites of high rate of deposition and, as a result, have a steeper gradient (0.763/ 1000 for Kosi) with a dicotomic slope pattern (Mohindra and Prakash, 1994). The length and steepness of slope affect the infiltration of water in the soil which in turn governs the amount of runoff. Also, the low elevation areas in the basin are the places to be inundated first during flooding. Higher elevation and steep slope cause quicker depletion of storage which results in larger peak discharge in the downstream side especially in the Lower Kosi basin. Hence, an elevation map for the study area was derived from contour data prepared from the topomaps and also GTOP30 DEM data was used for the visual analysis and the elevation range is classified as shown in Fig. 4.4 and named the variable as "Elevation Map".

A DEM (Digital Elevation Model) for part of the Kosi basin was generated in ILWIS image processing software with the help of 1017 spot heights from 1:50, 000 scale toposheets of the period 1972-75. The study area is located between 26°8'19.5" North Latitude and 86°10'54.99" East Longitude covering 5 Districts and 19 Development Blocks. The total elevation range in the study area varies from 32 to 50 meters. The data source and its description for the study area are shown in Table 4.1. False Color Composite (FCC) image is overlaid on the elevation data from GTOP30 DEM data for visual analysis and interpretation of some of the geomorphic and other topographic features as shown in as shown in Fig 4.5.

Table 4.1: Description of the DEM for the Kosi Basin

Parameters	Details
Data Source	SOI toposheets (1972 to 1975)
Boundaries of study area DEM	Located between 26°8'19.5" North Latitude and 86°10'54.99" East Longitude
Toposheets (1:50,000 scale)	72 J/7, 8, 11, 12, 16; 72 K/5, 6, 9, 10, 13
Total number of points	1017
Software (ILWIS 3.1)	Point Interpolation with moving average method.
Elevation range	30 to 50 m
Pixel size	200 m
Projection, Datum, Ellipsoid	UTM, Indian (India, Nepal), Everest (India 1956)

Essential data to build a DEM are the spatial coordinates and elevation information. In the present study, topographic sheets were used as data source. Using UTM projection system (datum India, Nepal), ellipsoid Everest India 1956), spot height data were collected. The point interpolation algorithm assumes that points are randomly distributed and spatially correlated. A comparison of the sample data set and the data used for generating DEM for the study area showed that the elevation points chosen for the study area are randomly distributed.

The point interpolation algorithm performs an interpolation on randomly distributed point values and returns regularly distributed point values. This is also known as gridding. This algorithm assumes that points are randomly distributed and spatially correlated. In the present study, 'moving average method' was used to interpolate the point elevation data which performs a weighted averaging on point values and returns output value for a pixel is calculated as the sum of the products of weights and point values, divided by sum of weights. Weight values are calculated in such a way that point close to an output pixel obtain larger weights and points farther away obtain smaller weights. Thus, the values of points close to an output pixel are of greater importance to the output pixel value than the values of points that are farther away.

Out of the total 1032 points available from the study area, 19 points were chosen for the accuracy analysis. Table 4.2 lists the difference between actual elevation and computed elevation of each of the 19 points. The root mean square error works out to be 1.304 m, which is reasonable as per international standard. The final DEM was prepared with the same moving average algorithm.

Table 4.2: Accuracy Analysis of DEM

Sample Number	Elevation Toposheet (m)	Elevation DEM (m)	Error (m)	$(\text{Error})^2$
1	60	60.383	-0.383	0.147
2	55	57.811	-2.811	7.902
3	67	66.821	0.179	0.032

4	50.9	46.781	4.119	16.966
5	62	63.339	-1.339	1.793
6	58.3	59.085	-0.785	0.616
7	41.5	42.072	-0.572	0.327
8	42	41.336	0.664	0.441
9	37	37.334	-0.334	0.112
10	39.2	38.49	0.71	0.504
11	41.9	42.327	-0.427	0.182
12	44	43.378	0.622	0.387
13	33	33.815	-0.815	0.664
14	39	39.144	-0.144	0.021
15	42	41.755	0.245	0.060
16	47	46.365	0.635	0.403
17	45	45.133	-0.133	0.018
18	42	41.835	0.165	0.027
19	39	39.123	-0.123	0.015
			SUM =	30.617
			SUM/(N-1)=	1.701
		Root Mean Square Error =		1.304

It is observed from the prepared DEM data and from the GTOP30 DEM data that the elevation in the study area varies from 32 – 50 m. The Kosi River in the study area shows more sinuous nature i.e. near lower Kosi river basin. Features like water-logged areas and high vegetation indicating low elevation areas. High wetlands along the river reach and the movement of the Kosi into South-East direction is observed showing gradual change in elevation from upstream to the downstream.

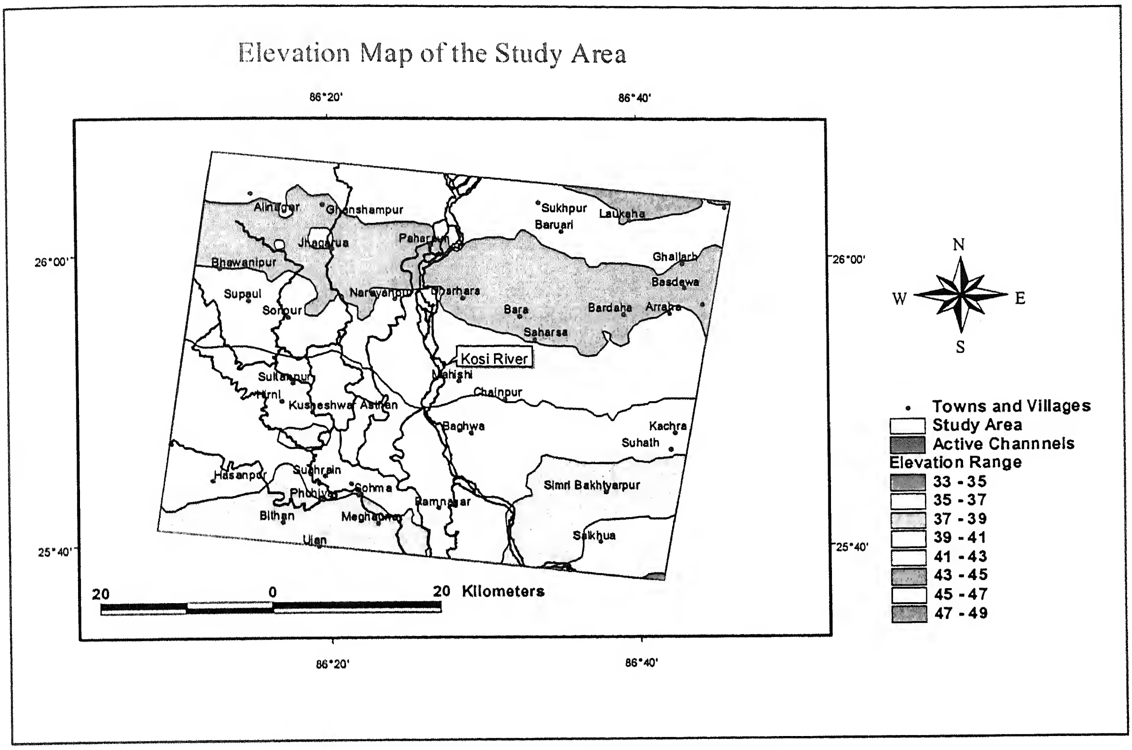


Fig. 4.4 Elevation map of the study area

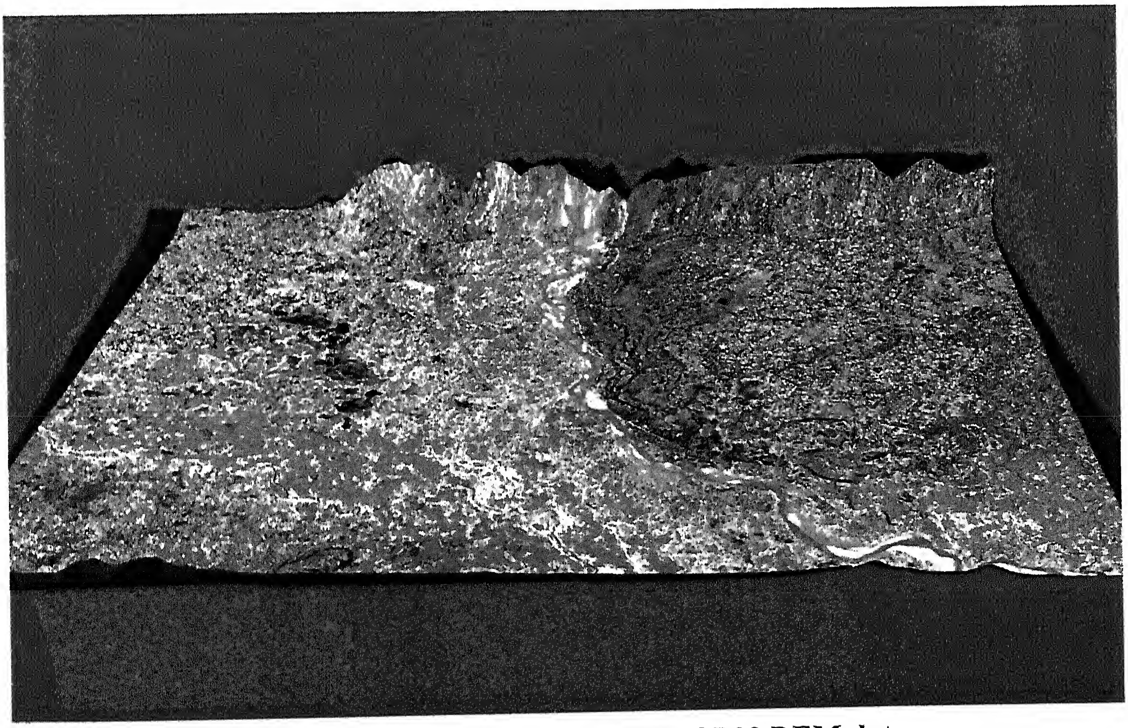


Fig 4.5 FCC of study area overlaid on GTOP30 DEM data

4.3.5 Vegetation (Agriculture)

The nature and extent of vegetation have a strong control on runoff characteristics of the river catchments such as the Kosi. Although no quantitative estimates are available for North Bihar plains, it seems that low forest cover may be a significant factor influencing the high flows in the Kosi River draining the plains. But, when we consider the situation in terms of damage that was induced during times of flood, it is necessary to consider the areas having dense vegetation and vice versa. It may be worthwhile to make attempts to establish the effect of vegetation in terms of damage and hazard that will incur during flooding. Hence, this vegetation is taken as another important variable in the flood hazard zonation process and named as "Vegetation". For this, a Vegetation map is prepared using one of the image processing techniques, popularly known as NDVI (Normalized Difference Vegetation Index) map. The NDVI is calculated with the following formula:

$$NDVI = (band3 - band\ 4) / (band3 + band4)$$

The NDVI values vary from –1 to +1. Any densely vegetated or forested region normally shows the NDVI value more than 0.5 while the bare rocks and the fresh sand generally have negative NDVI value.

A Vegetation map for the study area was prepared using one of the image processing techniques, popularly known as NDVI (Normalized Difference Vegetation Index) map. The values in the study area are ranging from – 0.2 to 0.51. Density slicing was applied on the NDVI image to classify the values from the above range into dense vegetation, moderate vegetation, less vegetation and no vegetation as shown in Fig 4.6. Then this NDVI image is exported into *.bmp format and georeferenced and registered it in ERDAS IMAGINE and imported into ArcView GIS where it was converted into GRID format for further overlay analysis and operations.

Figure 4.7 shows the histogram of the NDVI values and the NDVI image has been sliced using ILWIS image processing software at the intervals of < -0.1, -0.1 - 0.2, 0.2 – 0.4, and > 0.4. These intervals of classes are named as Dense Vegetation (Agriculture) for > 0.4 values, Moderate for 0.2 – 0.4 values, Less for 0.2 – (-0.1) values, and No Vegetation/ Barren for < -0.1 values. It can be observed from the histogram that the study area is having high concentration of moderate vegetation and very less amount

of dense vegetation (agriculture). As we know that the densely vegetated areas offer more resistance to flood waters and vice versa; but these places are at higher threat from the damage point of view.

4.3.6 Distance to Active Channels

For assessing the damages in different development blocks, and to locate safe places for faster evacuation of people at risk, it is essential to locate the distances from the active channels. Also, the areas nearer to active channels are more prone to flood and more damages will occur at these places than the areas far way from the channels. In this context, distance to active channels is considered as one of the important variable and named as "Distance".

Using ArcView GIS – Spatial Analyst and 3D Analyst tools and with the study area as the output extent, a distance to active channels map was generated by buffering the active channels at a distance intervals of 0.06° (6.48 Km) in map units (geographic Lat/Long) and saved in standard ArcView GIS "*.shp" format. Then this buffered *.shp file is converted into a GRID format. This output distance map is ranging from 0 – 33.48 Km and the classes divided are ranging from 0.0-6.48, 6.48-12.96, 12.96-19.44, 19.44-27.00, 27.00-33.48 Km respectively from the active channels in the study area as shown in Fig. 4.8.

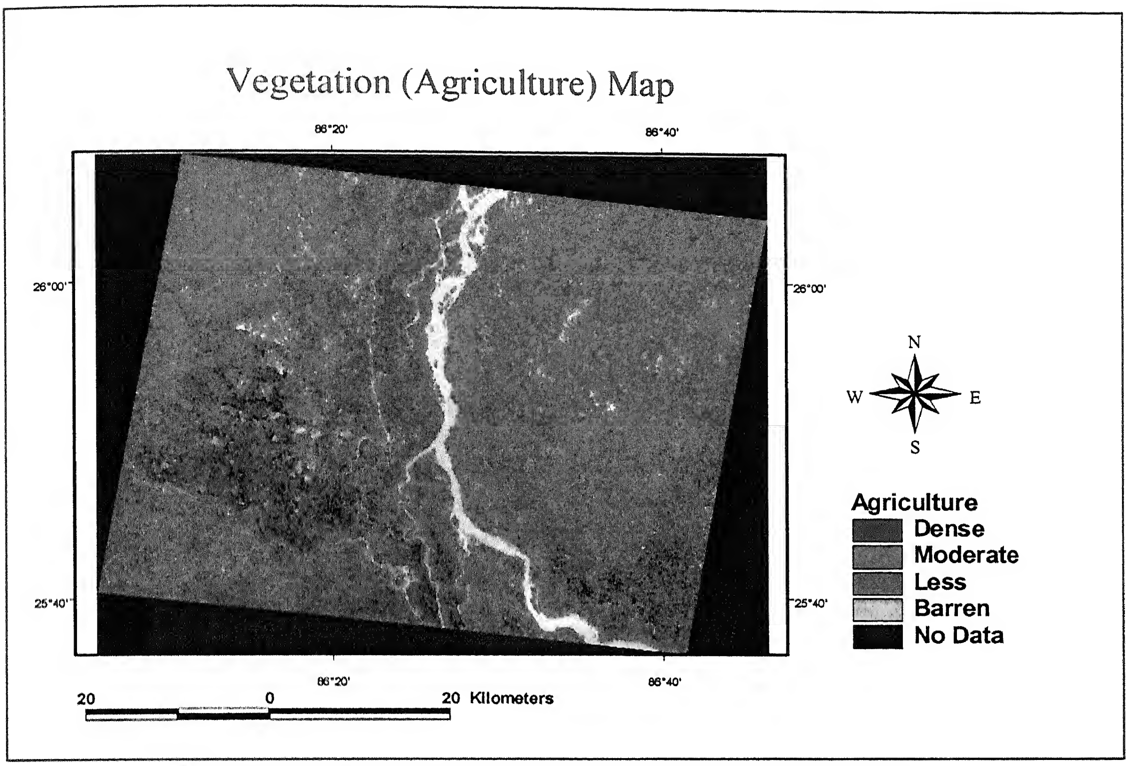


Fig. 4.6 Vegetation (Agriculture) Map of the study area

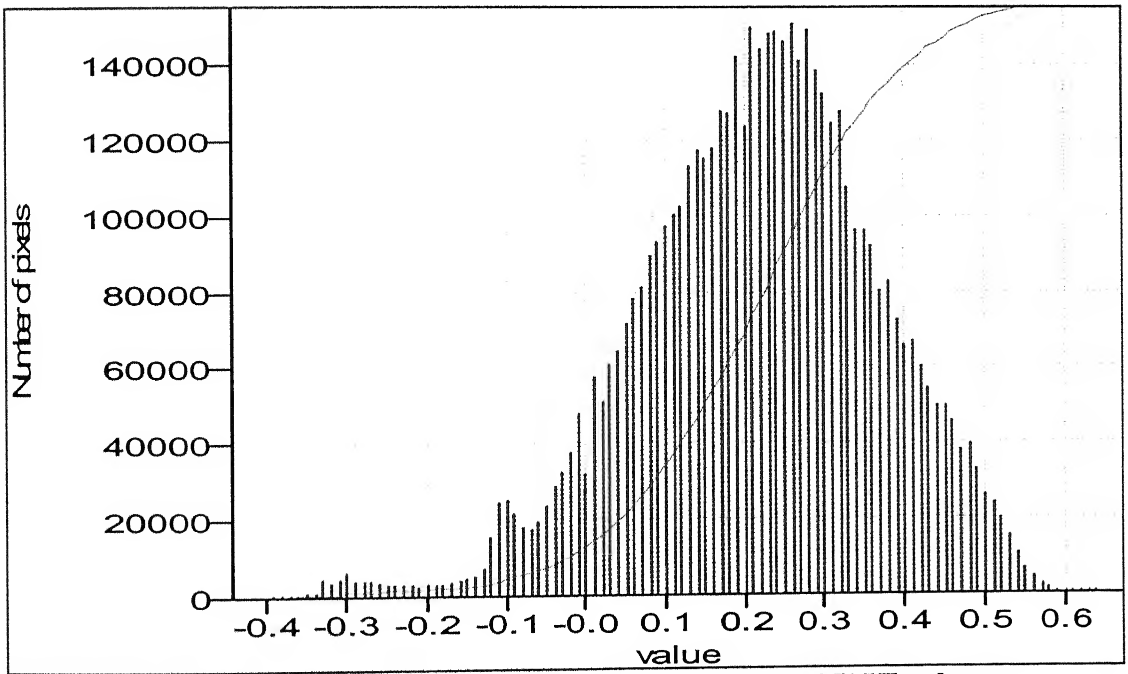


Fig. 4.7 Histogram of NDVI map showing variation in NDVI values

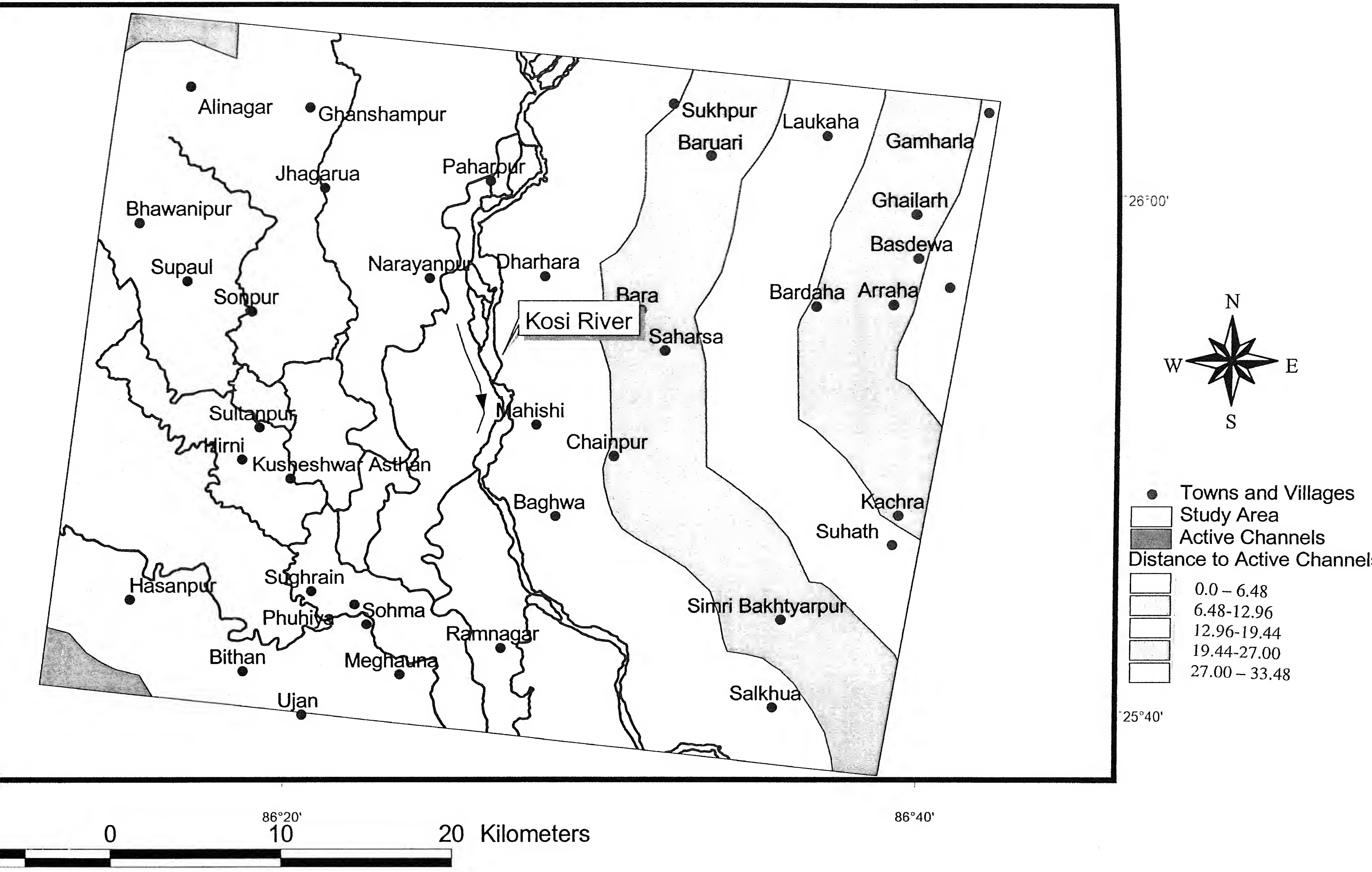


Figure 4.8 Distance to active channels map of the study area

Chapter 5

Data Integration in GIS

5.1 Data Integration in GIS – Introduction

A voluminous amount of data obtained from various digital image-processing and mapping, already discussed in earlier chapters, needs to be handled in a database for flood hazard mapping. These thematic datasets contain spatial information derived from the satellite imagery along with maps covering a large geographical region. The ideal tool for the overlay analysis of these thematic layers is Model Builder which comes with Arcview Spatial Analyst extension. An important point to be considered in the overlay analysis is that all the thematic layers generated from various image processing and GIS techniques should be in a raster GRID format and also in order to suit to current framework of AHP analysis, the GRID file should have discrete values rather than continuous values for assigning weightages. A detailed description of AHP analysis conducted on the data sets created in the form of thematic layers is given in section 5.2.3. Also, the basic tools necessary for the development of various spatial models and how to handle the data sets from various sources and how to process these data sets to meet our requirements are explained in detail using Model Builder1.0 in Arcview GIS (Spatial Analyst). The objective of this chapter is to illustrate the application of Geographical Information System (GIS) techniques in flood hazard mapping by using one of the multi-criteria decision-making techniques called Analytic Hierarchy Process (AHP).

5.2 Analytical Hierarchical Process (AHP) – Concepts & Adoption

Analytical Hierarchical Process (AHP) is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information. It is a methodology to systematically evaluate, often conflicting, qualitative criteria (Saaty, 1980). Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of activities or criteria by pairwise

comparison of these criteria on a 9-point scale (Table 5.1). In order to do this, a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy (Erkut and Moran, 1991). AHP is often used to compare the relative preferences of a small number of alternatives concerning an overall goal. Since its introduction in the late 1970s, AHP has been applied in a wide variety of practical settings to complex decision problems. Its ability to rank and quantitatively assess decision alternatives has led to its applications in many areas such as health care (Dougherty and Saaty, 1982), politics (Saaty, 1979), urban planning (Cook *et al.*, 1984), space exploration (Bard, 1986) and landfill suitability (Siddiqui *et al*, 1996), potential solid waste disposal sites (Sengupta *et al.*, 1997), and erosion intensity mapping (Sinha et al., 2002; Vaidyanathan et al., 2002). AHP is becoming popular in decision-making studies where conflicting objectives are involved. Recently, Siddiqui *et al.*, (1996) introduced a new method known as Spatial – AHP to identify and rank areas that are suitable for a landfill, using knowledge based user preferences and data contained in GIS maps.

Table 5.1 Analytic Hierarchy Measurement Scale (Saaty, 1980)

Reciprocal Measure of Intensity of Importance	Definition	Explanation
♦ 1	Equal importance	Two activities contribute equally to the objective
♦ 3	Weak importance of one over another	Experience and judgement slightly favor one over another
♦ 5	Essential or strong importance	Experience and judgement favor one activity over another
♦ 7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
♦ 9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
♦ 2, 4, 6, 8	Intermediate value between two adjacent judgments	When compromise is needed
♦ Reciprocal of the above	If the activity *i* have one of the above non zero numbers assigned to it when compared to the activity *j*, then *j* has the reciprocal value when compared with *i*.	

For the present study, the spatial-AHP technique (integrating the GIS database in the AHP framework) was applied to identify the hazard areas in the lower Kosi river basin for flood hazard mapping. The spatial AHP approach in the present study involved the following 5 steps: -

1. Identifying the issues, objective or goal.
2. Identifying the decision factors.
3. Structuring them in a decision hierarchy
4. Judging the RIWs of the decision hierarchy elements
5. Aggregating these measures in order to calculate Flood Hazard Index (FHI) of the alternatives
6. Ranking the categories according to FHI.

The goal or the objective of my thesis work is the identification of flood hazard zones in the Lower Kosi river basin. The decision factors to relate attribute to suitability concerning a particular goal are the factors controlling flood hazard in the study area. The primary factors, which have been considered in this study, as already mentioned in the previous chapter, are geomorphic features, elevation, vegetation, land cover, distance to active channels, and population density. Once the decision factors are identified and selected, sub-factors and even sub-sub-factors are identified to describe these criteria better. For the present study, the decision hierarchy used is shown schematically in Figure 5.1. The decision factors are arranged in a decision hierarchy consisting of number of levels. The first level of the hierarchy represents the goal, while the rest of the levels describe the factors and sub-factors in increasing details. For example, the geomorphologic class was further subdivided into nine subclasses as shown in Figure 5.1. Similarly, the other decision factors like vegetation, land cover, elevation, distance, and population density are sub-divided into sub-factors (see Fig. 5.1).

The RIWs are the normalized eigen vectors corresponding to the maximum eigen values of the pair-wise comparison matrices constructed at each level of the decision hierarchy. The RIW assigned to each hierarchy element was determined by normalizing the eigen vector of the decision matrix. Eigen vectors were then estimated by multiplying all the elements in a row and taking the nth root of the product, where n is the number of row elements (Saaty, 1980). Normalization of the eigen vectors was accomplished by

dividing each eigen vector elements to the decision factor.

For the hierarchy represented in the Figure 5.1, the relative importance weightage of level 2 decision factors like population density, distance, elevation, vegetation, land cover, geomorphic features was determined by comparing the decision factors pairwise. This was followed by pairwise comparison within each level 3-decision factor. As already mentioned in section 5.2.1 an attempt has been made to resolve conflicts and analyze judgement by a process of determining the relative importance of decision factors related to this thesis by pairwise comparison of these factors on a nine point scale given Table 5.1.

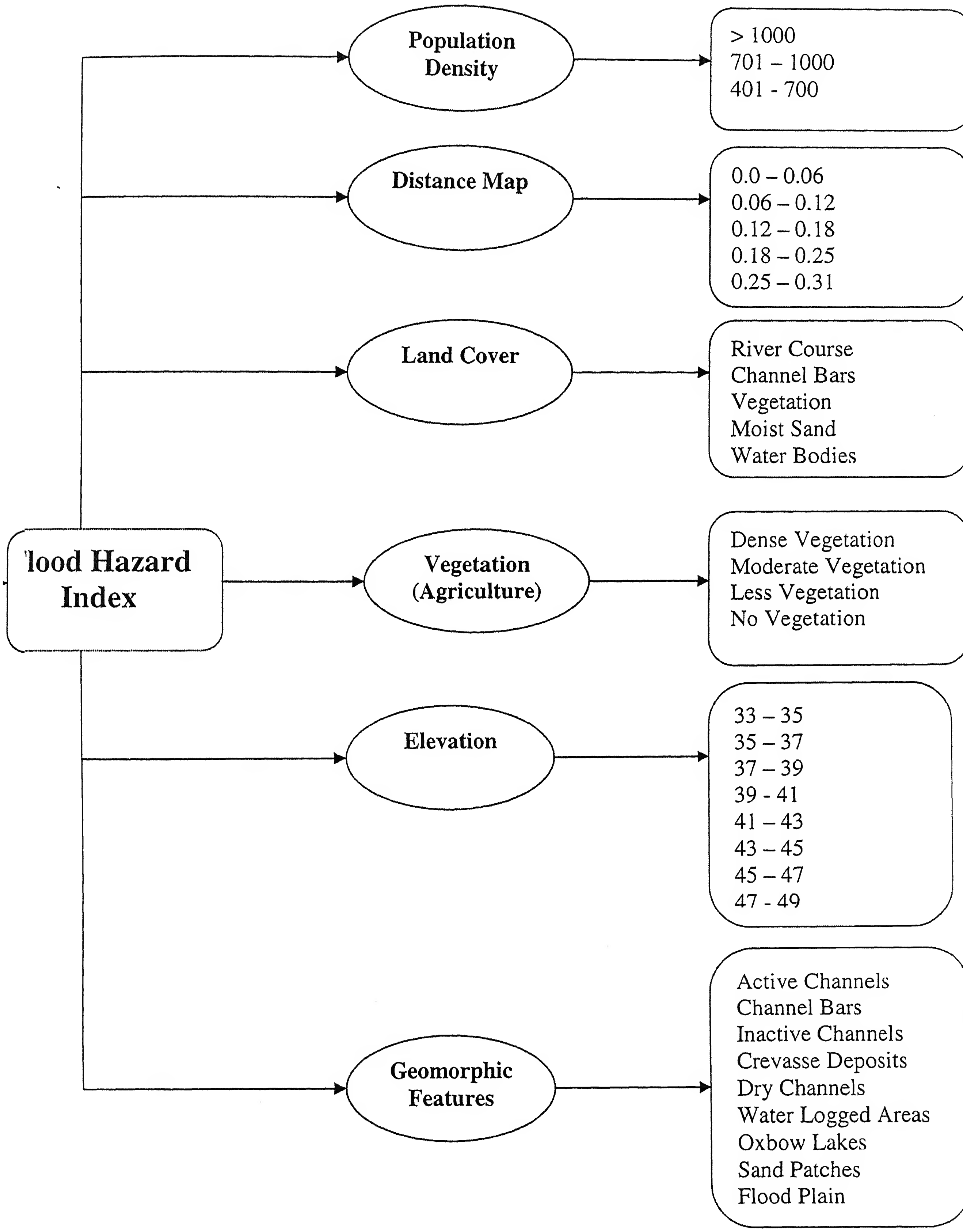


Figure 5.1 Decision Hierarchies for Flood Hazard Index Ranking

5.2.1 Results of AHP analysis

The decision factors, the sub-factors are generally arranged into a set of decision matrices. Table 5.2 shows such a matrix for the level 2 decision-factors. In this table, the relative weightages were assigned to each of the thematic layers by pairwise comparison for producing the final GIS composite layer.

Considering the flood hazard and the damage that is going to occur in the study area, the following logic was used to decide the relative importance of the factors. The values along a particular row suggest the importance of the factor (e.g. population density) relative to the other level 2 decision factors. The first value of the column 2 is the importance of the factor population density relative to itself, and consequently, a value of 1 was assigned indicating equal preference according to the Table 5.1. Therefore, the entire diagonal matrix in the Table 5.2 is unity since it compares the factors to themselves. All other cells contain different values depending on the preference of one decision factor in comparison to the other factors as per the Saaty's scale shown in Table 5.1.

After assigning the reciprocal intensity values to the different decision factors, relative importance to each hierarchy element was determined by normalizing the eigen vector of the decision matrix. Eigen vector values are estimated by multiplying all the elements in a row and taking the n^{th} root of the products, where n is number of row elements (Saaty, 1980). For the first row of Table 5.2, the eigen element of the population density was estimated as follows:

$$\boxed{EstimatedEE(pop - den) = \sqrt[6]{1*5*6*7*8*9} = 4.97}$$

Normalization of the eigen vector was accomplished by dividing each eigen vector element by the sum of all the eigen vector elements in a particular matrix, this is known as the Relative Importance Weight (RIW) for a particular decision factor. For Slope the RIW is computed as follows from Table 5.3:

$$\boxed{RIW\ (pop\text{-}den) = 4.97/\ (4.97+ 2.35 + 1.51 + 0.72 + 0.39 + 0.20) = 0.49}$$

As is obvious from the table, the population density gets the highest RIW followed by distance, elevation, land cover, agriculture, and geomorphic features.

Table 5.2 Calculation of Relative Importance Weightage for Level 2 Decision Factor

Decision Factors	Pair wise Comparison						EEE*	RIW
	Population Density	Distance	Elevation	Land cover	Agriculture	Geomorphic Features		
Population Density	1	5	6	7	8	9	4.97	0.49
Distance	1/5	1	4	5	6	7	2.35	0.23
Elevation	1/6	1/4	1	5	7	8	1.51	0.15
Land cover	1/7	1/5	1/5	1	4	6	0.72	0.07
Agriculture	1/8	1/6	1/7	1/4	1	5	0.39	0.04
Geomorphic Features	1/9	1/7	1/8	1/6	1/5	1	0.20	0.02

Note: EEE*= estimated eigen element; RIW = Relative Importance Weightage

The Level 2 and 3 RIW values were computed taking the following into consideration: -

- The first value in the column 3 shows the importance of population.density compared to distance map in the study area. Damage due to floods is counted and measured in terms of life and property. Higher the population density, higher is the damage going to occur which was shown in Table 5.3 by giving higher weightage to the high population density values and vice versa. Though the distance to active channels also contributes in terms of flood proneness, population density was given a strong importance with a value of 5 compared to distance map in lieu of damage; and any remedial measures taken on behalf of the concerned authorities is implemented at district level and or at block level in terms of population density rather than distances from the active channels.

- Lower elevation areas in the basin are the places to be inundated first during flooding which was given higher weightages as shown in Table in 5.5 and vice versa. Higher elevation and steep slope causes quicker depletion of storage which results in larger peak discharge in the downstream reaches especially in the Lower Kosi basin where population is affected. So the population density was given a value of 6 for the cell in the column 4 compared to elevation in Table 5.2.

- ❖ If we consider the land cover factor from the damage point of view, the parameters (which include agricultural lands) under the land cover as shown in Table 5.6 indicates more hazard potential in terms of damage and changes to the parameters considered than the factor agriculture. So, a value of 7 indicating strong importance to the cell in column 5 compared to agriculture in Table 5.2.

- ❖ If we consider the agriculture from the damage point of view, denser is the agriculture i.e. vegetation, higher will be the loss to the property and vice versa; which can be seen from Table 5.7. So, a value of 8 to the cell in column 6 compared to geomorphic features in Table 5.2. Geomorphic features like Active Channels, Inactive Channels, Crevasse Deposits, Water-logged areas, Channel bars, Sand Patches, Ox-bow lakes have already been taken into consideration in other layers. So, less importance was given here. Due to lateral migration of rivers like the Kosi and the Gandak, and other small rivers in the interfan area by the processes of avulsion and through meandering and cut-offs, several geomorphic features are formed mentioned above and some of them are modified due to these effects. Populations residing in this type of flood plains where channel characteristics are rapidly changing as shown in geomorphic features in Table 5.8 are under potential flood threat. So, a value of 9 was given to cell in the column 7 of Table 5.2. compared to geomorphic features.

Using a similar logic, rest of the level 2 and level 3 decision factors matrices are computed as given in Table 5.2 through 5.8.

Table 5.3 Calculation of Relative Importance Weightage for Population Density (Level 3 sub factor)

Decision Factors	Pair wise Comparison			EEE*	RIW
	>1000	701-1000	401-700		
>1000	1	7	9	3.98	0.77
701-1000	1/7	1	5	0.89	0.17
401-700	1/9	1/5	1	0.28	0.05

Table 5.4 Calculation of Relative Importance Weightage for Distances to Active Channels (Level 3 sub factor)

Decision Factors	Pair wise Comparison					EEE*	RIW
	0.0-0.06	0.06 – 0.12	0.12-0.18	0.18-0.25	0.25-0.31		
0.0-0.06	1	3	5	7	9	3.94	0.51
0.06 – 0.12	1/3	1	3	5	7	2.04	0.26
0.12-0.18	1/5	1/3	1	3	5	1	0.13
0.18-0.25	1/7	1/5	1/3	1	3	0.491	0.063
0.25-0.31	1/9	1/7	1/5	1/3	1	0.254	0.033

Table 5.5 Calculation of Relative Importance Weightage for Elevation (Level 3 sub factor)

Decision Factors	Pair wise Comparison								EEE*	RIW
	33-35	35-37	37-39	39-41	41-43	43-45	45-47	47-49		
33-35	1	3	4	4	5	6	7	9	4.16	0.35
35-37	1/3	1	3	4	4	5	6	7	2.76	0.23
37-39	¼	1/3	1	3	4	4	5	7	1.85	0.15
39-41	¼	¼	1/3	1	3	4	4	5	1.22	0.102
41-43	1/5	¼	¼	1/3	1	3	4	5	0.84	0.07
43-45	1/6	1/5	¼	¼	1/3	1	3	5	0.56	0.05
45-47	1/7	1/6	1/5	¼	¼	1/3	1	3	0.36	0.03
47-49	1/9	1/7	1/7	1/5	1/5	1/5	1/3	1	0.22	0.02

Table 5.6 Calculation of Relative Importance Weightage for Land Cover (Level 3 sub factor)

Decision Factors	Pair wise Comparison					EEE*	RIW
	Running Water	Fresh Sand	Water logged Areas	Moist Sand	Vegetation		
Running Water	1	2	5	6	7	3.35	0.15
Fresh Sand	½	1	4	5	6	2.27	0.10
Water logged Areas	1/5	¼	1	7	5	1.12	0.05
Moist Sand	1/6	1/5	1/7	1	2	0.39	0.017
Vegetation	1/7	1/6	1/5	½	1	0.29	0.013

Table 5.7 Calculation of Relative Importance Weightage for Agriculture (Level 3 sub factor)

Decision Factors	Pair wise Comparison				EEE*	RIW
	Dense	Moderate	Less	Barren		
Dense	1	5	7	9	4.21	0.62
Moderate	1/5	1	5	7	1.63	0.24
Less	1/5	1/5	1	3	0.58	0.08
Barren	1/3	1/7	1/3	1	0.35	0.05

Table 5.8 Calculation of Relative Importance Weightage for Geomorphic Features (Level 3 sub factor)

Decision Factors	Pairwise Comparison								EEE*	RIW
	Active Channels	Channel Bars	Inactive Channels	Crevasse Deposits	Water logged Areas	Oxbow Lakes	Sand Patches	Flood Plain		
Active Channels	1	3	5	6	6	5	9	5	4.56	0.32
Channel Bars	1/3	1	5	6	6	5	9	5	3.57	0.25
Inactive Channels	1/5	1/5	1	8	5	5	3	6	2.15	0.15
Crevasse Deposits	1/6	1/6	1/8	1	7	7	7	9	1.56	0.10
Water logged Areas	1/6	1/6	1/5	1/7	1	3	7	5	0.67	0.04
Oxbow Lakes	1/5	1/5	1/5	1/7	1/3	1	5	7	0.52	0.03
Sand Patches	1/9	1/9	1/3	1/7	1/7	1/5	1	3	0.31	0.02
Flood Plain	1/5	1/5	1/6	1/9	1/5	1/7	1/3	1	0.22	0.01

5.2.2 Flood Hazard Index (FHI)

The FHI for each pixel was determined by aggregating RIWs at each level of the hierarchy. FHI for all raster cells in all the thematic layers were determined simultaneously using overlay analysis conducted in Model Builder of ArcView GIS. Higher the FHI value, higher is the flood hazard for that pixel.

FHI was calculated by multiplying the RIWs of level 3-decision factor by the associated RIWs of the level 2 factors at each level and summing the values of all grouped elements. Since our problem is defined in three level hierarchies, the simplified equation for 3 level hierarchy is:

$$FHI = \sum_{i=1}^{N_2} \left[\left(RIW_i^2 \right) * \left(RIW_{ij}^3 \right) \right]$$

where, FHI = Flood Hazard Index,

N_2 = the number of level 2 decision factor,

RIW_i^2 = relative importance weight of level 2 decision factor i.

RIW_{ij}^3 = relative importance weight of level 3 sub-factor j of level 2 decision factor i.

If the decision hierarchy has more or fewer levels, the formula must be modified appropriately.

5.3 Model Builder – A Complete Overview and Application

5.3.1 Model Builder

Model Builder is a tool in the ArcView Spatial Analyst extension that helps to create spatial models of geographic areas. A model is a set of spatial processes, such as buffers or overlays that converts input data into an output map. Large models can be built by connecting several processes together.

In ModelBuilder, a spatial model is represented as a diagram that looks like a flowchart. It has nodes that represent each component of a spatial process. Rectangles represents the input data, and ovals represent functions that process the input data, and rounded rectangles represent the output data that is created when the model is run. The models are connected by arrows that show the sequence of processing in the model.

The model is much more than a static diagram; it stores all the information necessary to run the processes and create the output data in ArcView GIS. We can also create documentation that can be saved as part of the model. This enables anyone to reuse the model and share it with others. We can apply the same model to different geographic areas by changing the input data. We can easily modify the model to explore "what if" scenarios and obtain different solutions. Model Builder has the tools to create, modify, and run a model. Model Builder uses ArcView GIS to manage the input and output data.

Some features of Model Builder include

- A window where you build and save your models
- Wizards that walk you through adding new processes or editing the properties of existing processes
- Property sheets that let you quickly modify properties of input data, processes, or output data.
- Drag-and-drop tools that let you build and connect processes manually
- Layout tools that help you arrange your model neatly

5.3.2 Spatial Model represented in Model Builder

In general terms, a model is a representation of reality. The purpose of a flood hazard model is to help people and scientific community to understand, describe, or predict how things work in the real world. By representing only those factors that are important to our study, a model creates a simplified, manageable view of the real world.

The model does not actually contain spatial data; it has place holders, called nodes, which represent the data that is processed and created when the model is run. The actual data is managed and displayed in ArcView GIS. Model Builder gives processing instructions to ArcView GIS when we run the model.

In Model Builder, a model is a collection of processes performed on spatial data that produces information, usually in the form a map. One can use this map for decision making, scientific study, and to provide general information. Each process in a model has three components; input data, a function that transforms the input data or derives new information from it, and the output data that the function creates. In more complex spatial models like the current flood hazard model, it can even combine quantitative information with qualitative information. Model Builder allows incorporating comments, assumptions, citations, and Web links directly to the model. Models can be reused, modified, and shared with others.

Spatial models can do the following:

- Rate geographic areas according to a set of criteria.

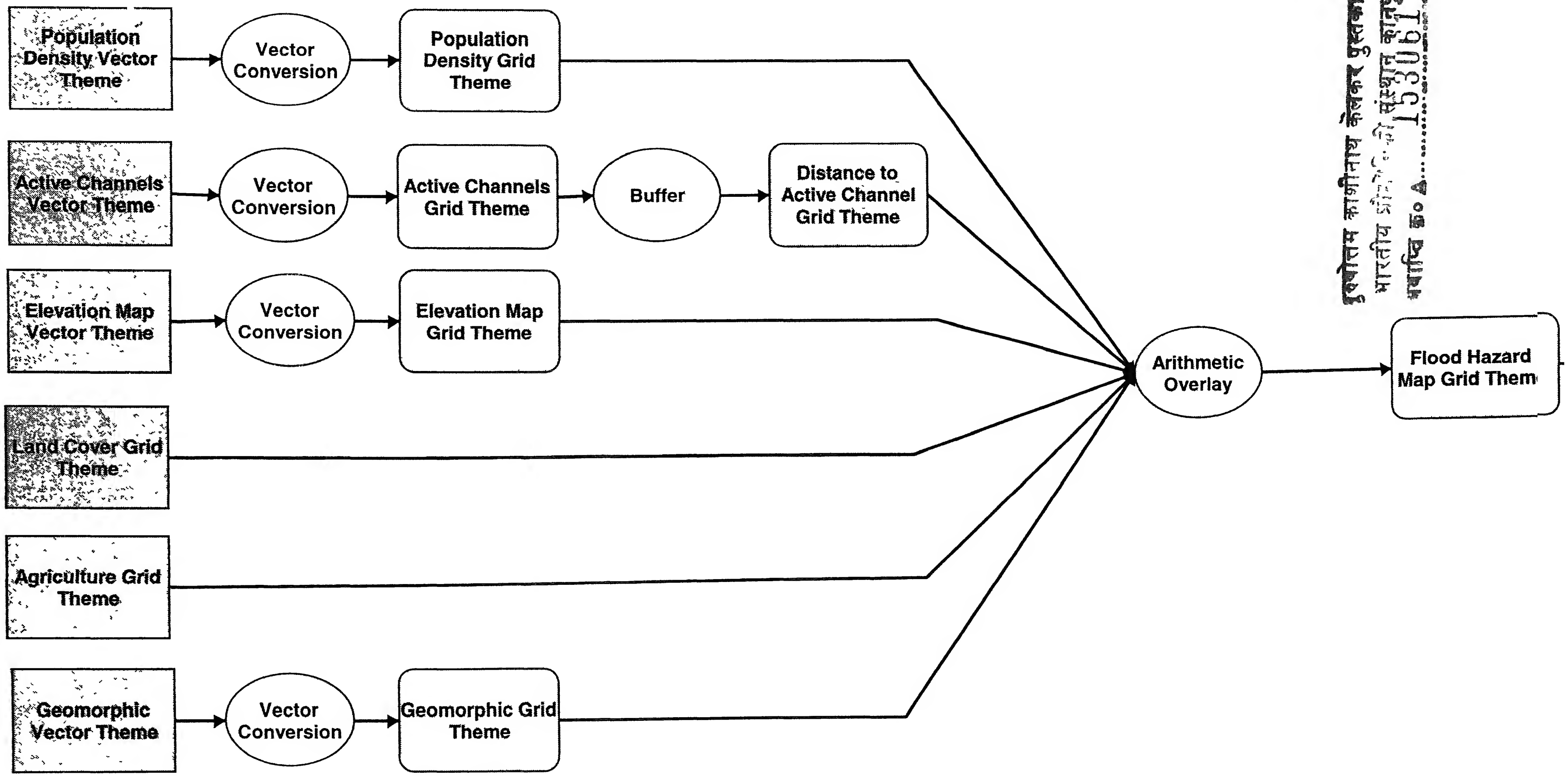
For example, to create a flood hazard map for an area, we must decide how many factors we will consider and which are most important. Rating the decision factors was done by AHP analysis as explained earlier.

- Make predictions about what occurs or will occurs or will occur in geographic areas.

For example, to identify which areas are most likely to have more flood hazard, we need to consider the effect or impact of various factors and create thematic layers for those factors. Overlaying these thematic data sets in a model gives areas of high hazard potential.

- Solve problem, find patterns, and enlarge our understanding of the systems.

In this thesis work, Model Builder was used to convert all the thematic layers in vector format (vector themes) into grid format (grid themes), and to create buffers around the active channels at a specified distance, to arithmetically overlay all the grid themes derived from the above mentioned processes incorporating AHP process. The flow chart showing conceptual view of GIS based Flood Hazard Model is shown in Figure 5.2.



Note: Arithmetic overlay operation by AHP analysis

Fig. 5.2 Conceptual view of GIS based Flood Hazard Model

5.4 Synthesis of Results

The FHI values as obtained from the above equation for the study area in the lower Kosi River basins are plotted as histogram in Figure 5.3 and the flood hazard index map is shown in Figure 5.4. The results obtained from the overlay analysis shows the final FHI for each pixel. Results from the Model Builder by the adoption of AHP analysis shows values as shown in the Figure 5.4. Threshold values, on the basis of histogram distribution, were incorporated for purpose of classifying the pixels into groups as < 0.128, 0.128 – 0.18, 0.18 – 0.232, and > 0.232. Pixels with values between two thresholds were grouped. The classified groups shown above have been named as shown in Table 5.9 and represented as Flood Hazard Map as shown in Figure 5.5. Also bar chart showing the hazard class for different development blocks is presented in Figure 5.6

Table 5:9 Showing different FHI range and their class names

FHI Range	Class Name
< 0.128	Low Hazard
0.128 – 0.18	Moderate Hazard
0.18 – 0.232	High Hazard
> 0.232	Very High Hazard

Higher values signify more susceptibility to floods and are the places of potential flood threat.

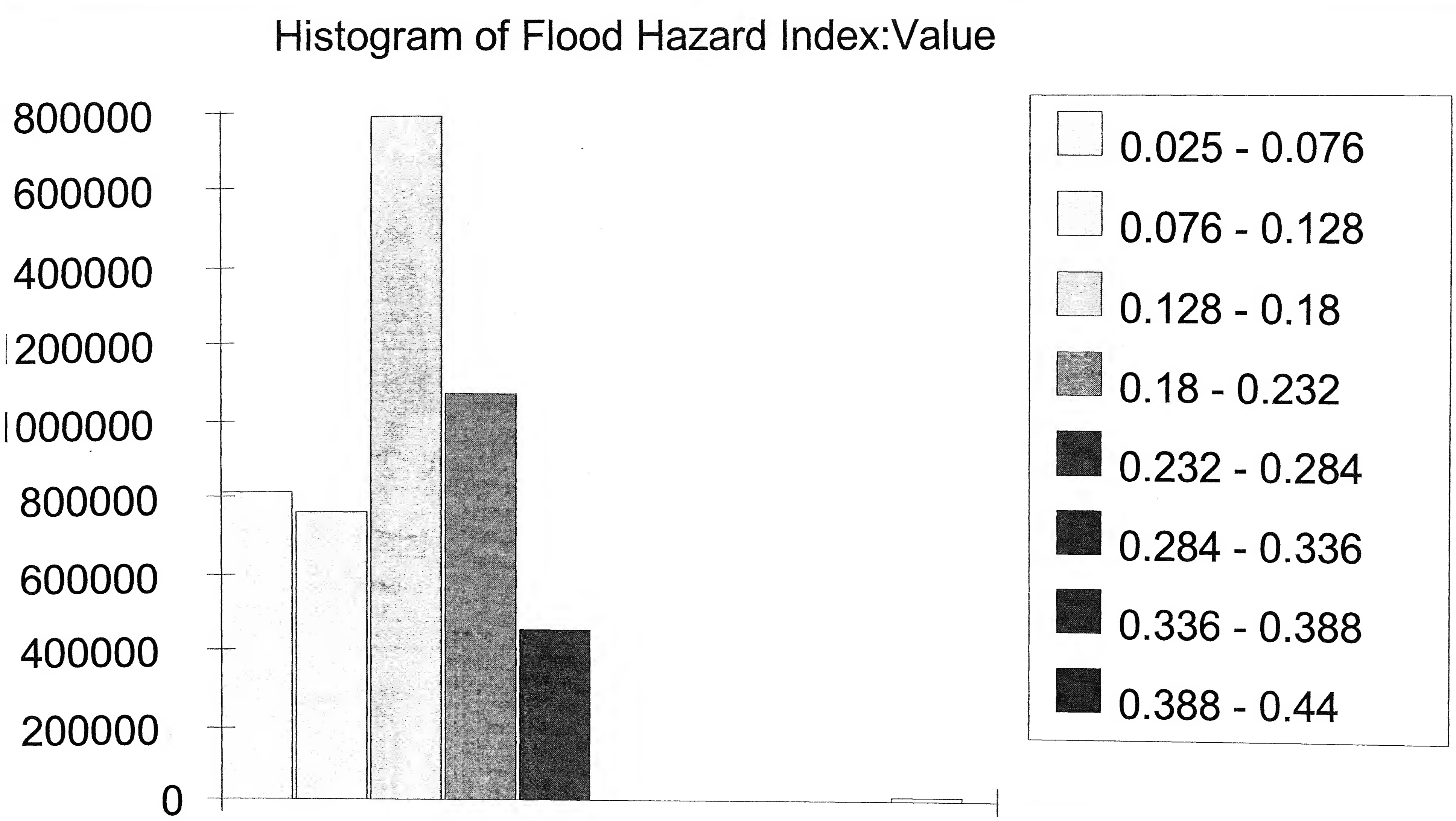


Figure 5.3 Histogram of the Flood Hazard Index values in the study area

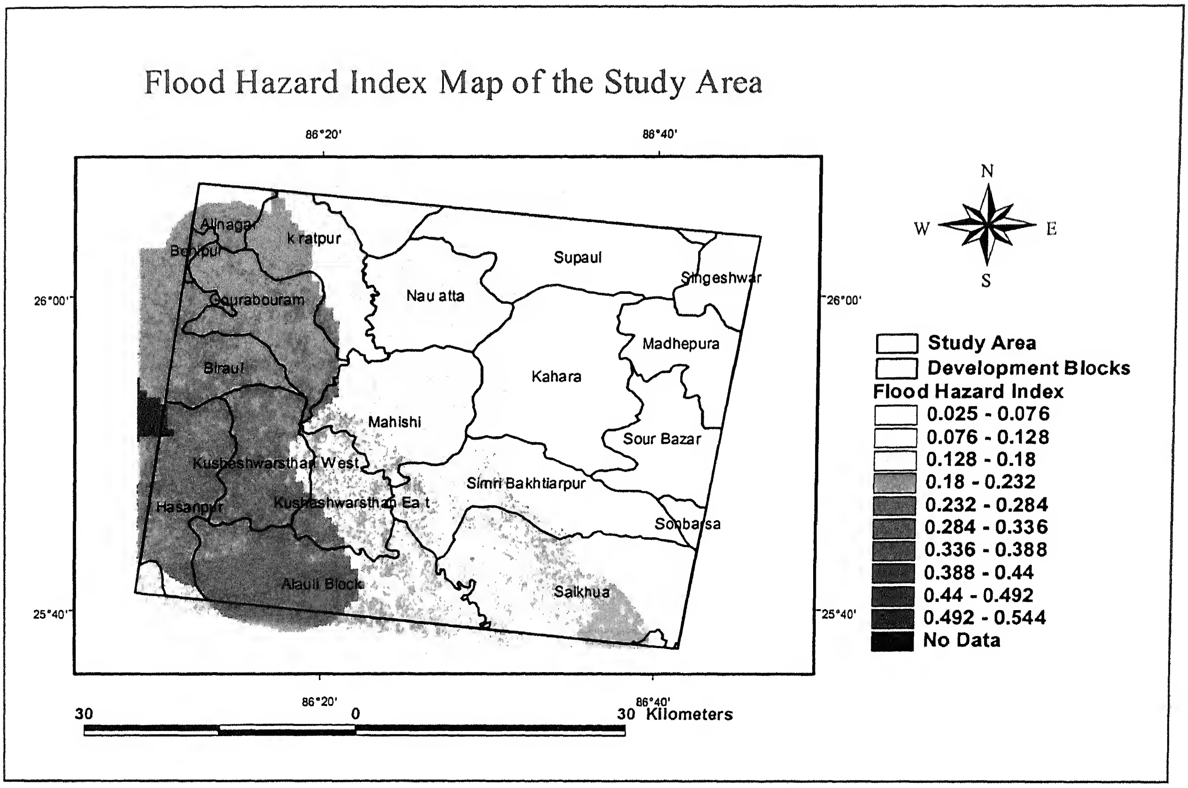


Figure 5.4 Map showing Flood Hazard Index value range

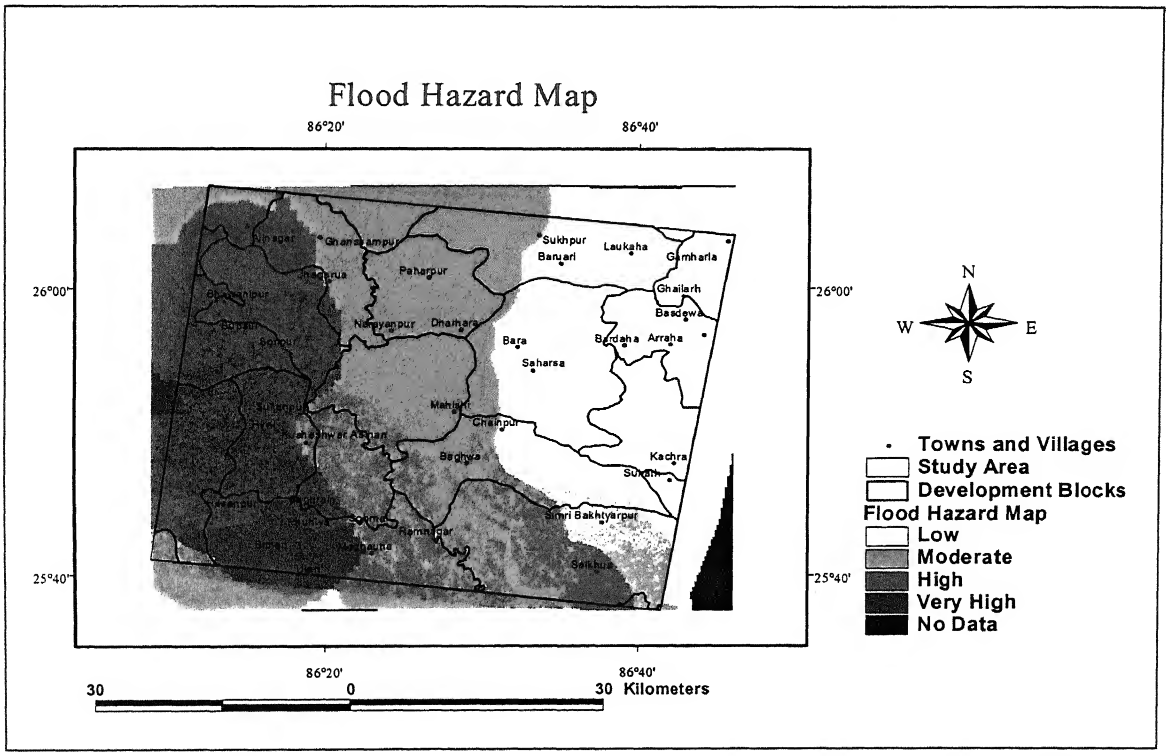


Figure 5.5 Flood Hazard Map for the study area

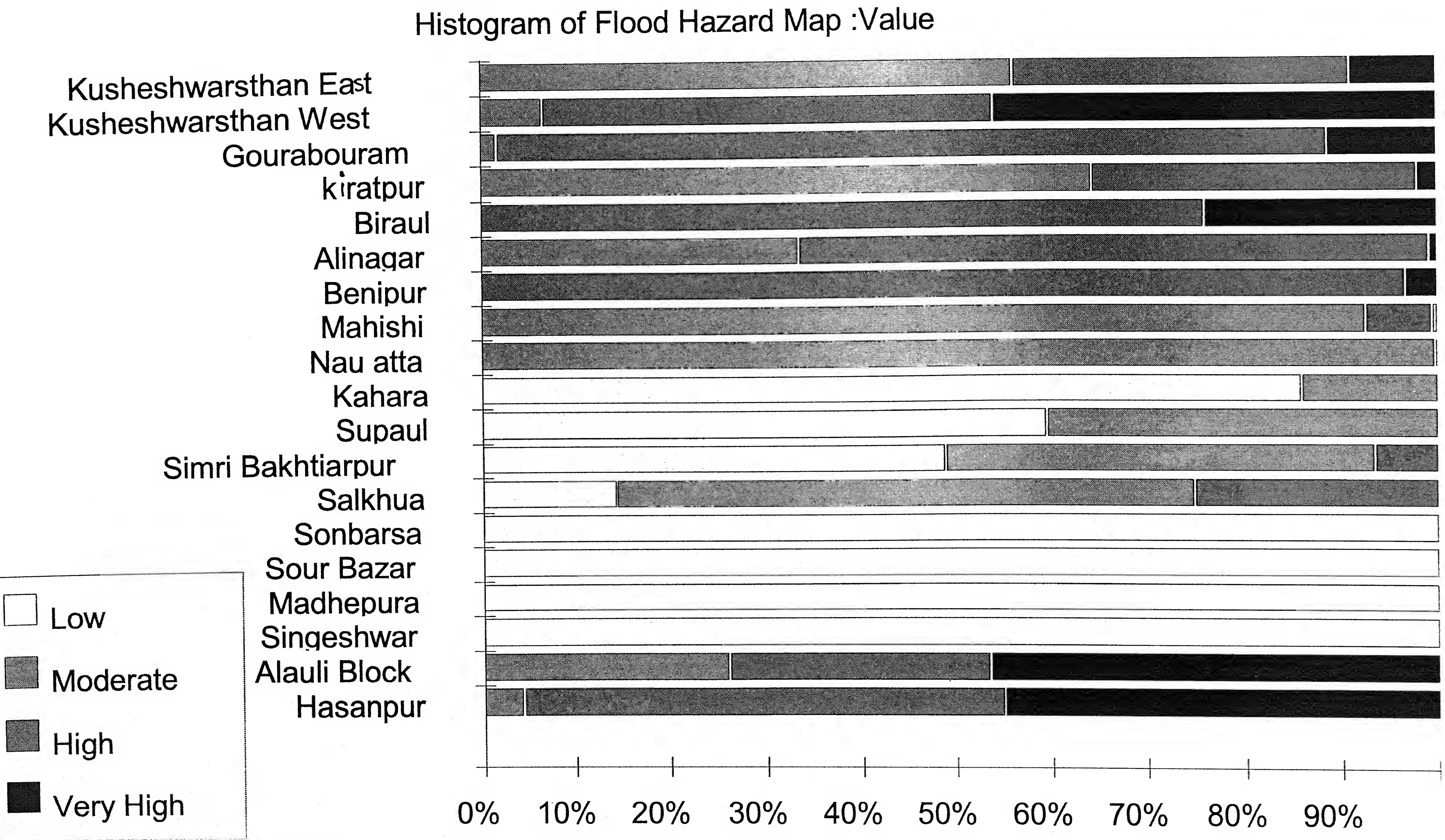


Figure 5.6 Bar chart showing the hazard values for different development blocks

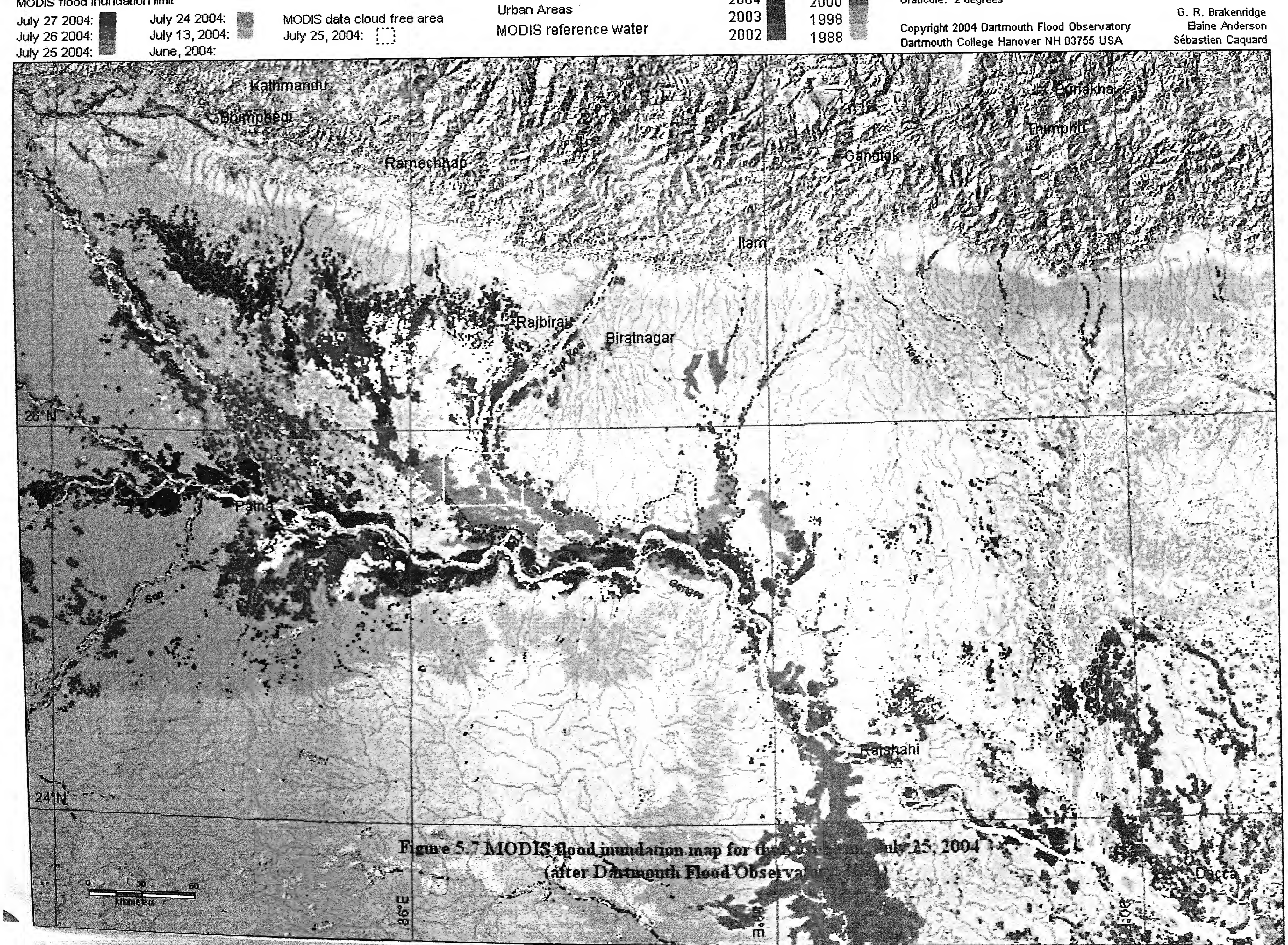


Figure 5.7 MODIS flood inundation map for the [illegible] July 25, 2004 (after Dartmouth Flood Observa[illegible])

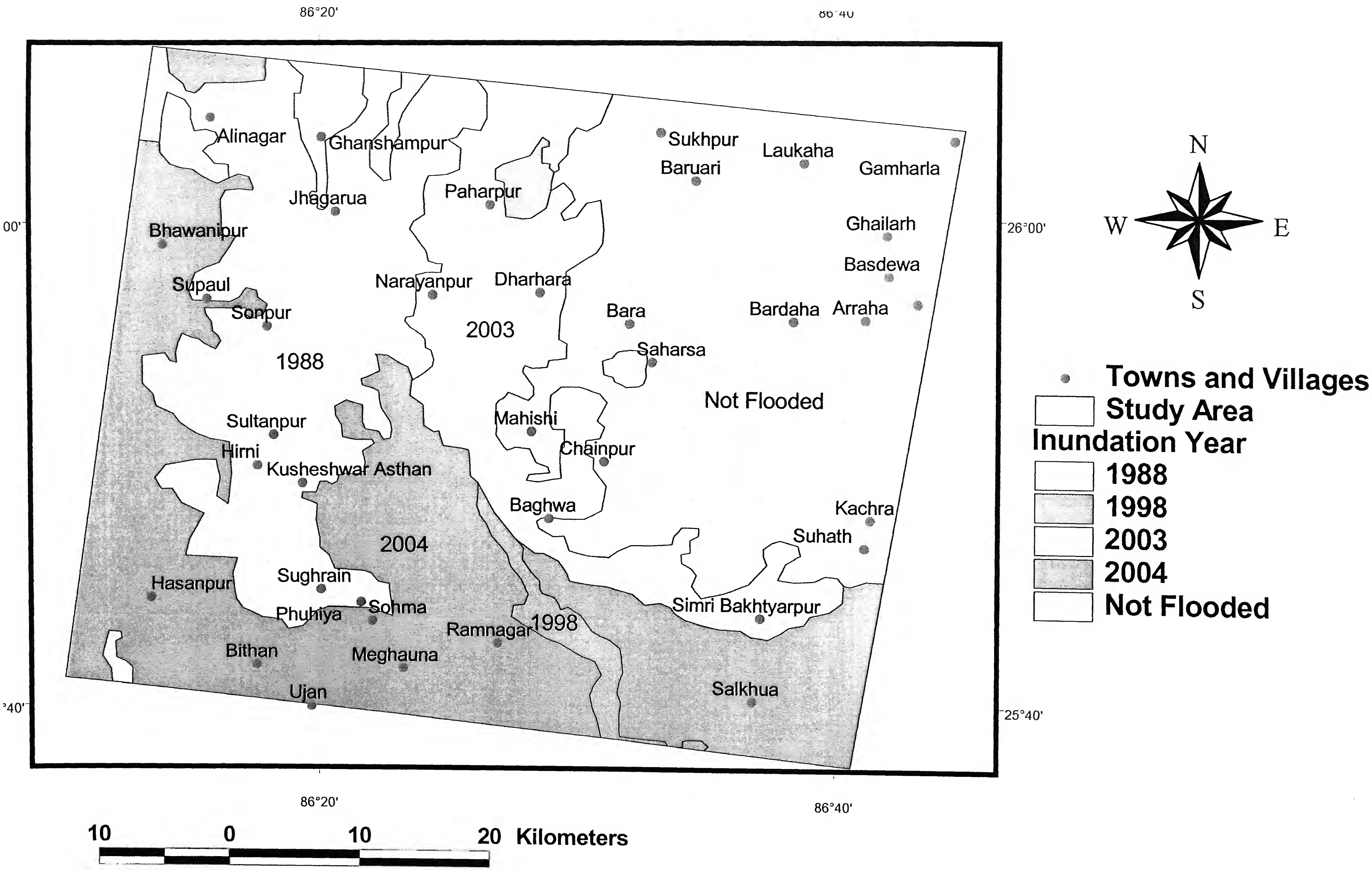


Figure 5.8 MODIS Flood Inundation Map for the study area window (modified after Dartmouth Flood Observatory, USA)

The flood hazard map obtained by overlaying various thematic layers in a GIS environment is showing very satisfactory results when compared to the inundation map (Fig. 5.8) derived from the MODIS flood inundation map (Fig. 5.7) of July 25, 2004 for the Kosi basin. The source of this MODIS flood inundation map is the Dartmouth Flood Observatory, Dartmouth College, Hanover NH 03755, USA. This inundation map is showing the flooded areas form the period 1988 to 2004 which served as the latest information source for the validation of the current research work. Not only that the inundation areas coincide in the final flood hazard map but the severity of the hazard areas is also reflected. A comparison of the flood hazard map with July 25th, MODIS flood inundation image reflects the following:

- It is observed that the western part of the study area is under high and very high flood hazard zone. The population density is also high (701-1000, > 1001 persons per sq.km) in this region. This area is frequently inundated as is evident from the MODIS inundation map.
- It is observed that the distance to active channels (which are the main sources of flood discharge) is playing an important role in the control of flood hazard in the study area.
- The elevation in the study window gradually reduces from 49m in the north to 32m in the south. The entire region is a plain having a gentle slope from north-west to south-east. The area west of Darbhanga is drained by the Kamla and Karai rivers is intersected by Kamla-Balan river and other numerous streams. This region also falls in low elevation zone and a number of marshes and swamps have developed in this region. As a result, this area has very high flood hazard index.
- It is also observed that the geomorphic features like active channels, inactive channels, channel bars, water-logged areas, oxbow-lakes, moist sand are undergoing rapid modifications due to channel avulsion, meandering cut-offs in the study area. Such kind of dynamic behaviour also contributes to frequent and extensive flooding in the area.
- The inundation limit or extent of MODIS inundation map of 2004 and previous years closely matches with the hazard areas in the map validating (or confirming) the logic followed in the analysis and the model developed; reflecting flood effects for operational years.

- Hazard areas mapped are as per the integrated effect of different parameters and not just on the basis of a few years of inundation data. Thus, the potential of flood hazard of the areas is based on an integrated analysis and not merely on a hydrological phenomenon.
- There are some areas which have not been inundated during the last 1-2 years but they still fall under high and very hazard areas e.g. parts of Kiratpur, Gouraboram, Biraul, Mahisi, Kusheswarasthan west, Alauli development blocks have not been inundated during the last few years but are still falling under high and very high hazard zones. This suggests that the future potential of flooding is high in these regions and adequate measures should be taken to protect these areas.
- The development blocks viz. Singheshwar, Madhepura, Sour-Bazar, Eastern-parts of Kahara, Simri Bakthiarpur, Supaul which fall under low hazard areas and have also been inundated for the last 10 years indicate much lower probability of flooding in future. This is perhaps a manifestation of gradual migration of the Kosi river towards west during the last 200 years.

Chapter 6

Summary and Conclusions

The research conducted in this thesis work formulates an efficient methodology to accurately delineate the flood hazard areas in the lower Kosi River basin, North Bihar, India. This study represents some exploratory steps towards developing a new methodology for inexpensive, easily-read, rapidly-accessible charts and maps of flood hazard based on morphological, topographical, demographical related data. The study has also focused on the identification of factors controlling flood hazard in the study area. It accomplishes this goal by combining Spatial AHP technique with GIS-based overlay analysis. The application of this methodology and model is not limited to the Kosi River itself but may be applied to any river reach.

A combination of different data sets such as remote sensing images (IRS LISS-III data), Census data (1991), topographical, morphological and other relevant statistical data about the available infrastructure facilities from the government agencies have been used to identify the flood hazard areas in a cost effective manner for parts of lower Kosi River basin.

The controlling factors identified are population density, distance, elevation, land use, vegetation, and geomorphic features. Thematic maps for these factors were prepared by using various image processing (classification) techniques and GIS operations at different scales. Each of the thematic layers (classified data sets) along with its classes was then brought to the same scale by registration.

Analytical Hierarchical Process (AHP) is a multi-criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information. Weightages were assigned to each of the thematic layers derived above based on the AHP technique.

These weightages were given taking into consideration of the flood hazard potential of the area and the factor. Using ArcView GIS – Model Builder, overlay analysis of all these thematic layers was carried out and a final flood hazard map was prepared. The important point to be considered in the overlay analysis is that all the thematic layers generated from various image processing and GIS techniques should be in a raster GRID format and also in order to suit to current framework of AHP analysis, the GRID file should have discrete values rather than continuous values for assigning weightages.

The AHP analysis and the flood hazard map developed are validated with the MODIS flood inundation map of July 25, 2004. The results obtained are satisfactory and are validating the logic followed in the analysis and the model developed. It is observed from the flood hazard map and the MODIS flood inundation map that the distance to active channels is playing an important role in the control of flood hazard in the study area than the other parameters considered. Though the distance to active channels is playing a major role, the other factors like elevation, land cover, vegetation (agriculture), and geomorphic features are also contributing to the control of flood hazard in the area. This is because, the study area is rapidly modifying due to the fluvial processes like channel avulsion, meander cut-offs, and rapid siltation. Many of these areas are permanently water-logged and get filled up quickly during monsoon.

Thus it can be concluded that the approach used in this thesis work is useful for accurately delineating the flood hazard areas in the lower Kosi River basin. Some of the important conclusions drawn from the current study are as follows:

1. The flood hazard map has been developed from the public domain data and with the use of satellite imagery in a cost effective way. The approach followed can

prove to be very efficient in most flood prone regions in India where data availability is poor and resources are limited. Use of high resolution satellite data and DEM's can improve the model significantly.

2. The use of Spatial – AHP technique has not been adopted before for flood hazard mapping and this study is the first attempt in this direction. Additional parameters can be added to the analysis depending upon the data availability and requirements for specific regions.
3. The study is based on the understanding of processes influencing the flood, and therefore, flood mitigation measures can be better planned keeping in view the causative factors of the flood in the study area.
4. The flood hazard map is based on the integrated effect of different parameters and not just on the basis of fewer years of inundation data. It therefore indicates that the floods are not merely a hydrological phenomenon but an integrated response of the basin. This is clearly reflected from the fact that some areas which have not been inundated during the last 1-2 years still fall under high and very hazard areas.
5. In my analysis, population density was given a higher weightage. This reflects the fact that the safety of the life and property is very important while considering the flood hazard and therefore a human approach to flood related studies.
6. The approach outlined in this thesis can be applied at any scale. For instance, the development block level analysis can be applied also on a revenue village level depending upon the data availability. The basic merit of this methodology lies in its simplicity and low cost.

The work presented in this thesis can be improved further for accuracy and visualization. Following suggestions are offered for future studies:

- ❖ Use of high resolution DEM's and satellite data for flood related studies can significantly increase the accuracy of the model at hand and helps in developing flood inundation maps.

- Fly-through modeling of the study area can show the flooding behavior of the river in 3D and can be used to make predictions by using different hydrological data (storm data).
- With a robust model in hand for a basin, the approach may be used for a timely warning for floods in flood-prone regions.

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